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Sedimentology And Hydrogeochemistry Of The Tista River, Rangpur Division, Bangladeshsedimentology And Hydrogeochemistry Of The Tista River, Rangpur Division, Bangladesh

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University of Rajshahi, Rajshahi

SEDIMENTOLOGY AND HYDROGEOCHEMISTRY OF THE TISTA RIVER, RANGPUR DIVISION, BANGLADESH

M.Phil. Thesis

A thesis Submitted [illegible] University of Rajshahi for the [illegible] for the Degree of [illegible]

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DECEMBER, 2021

Dedicated to my
Departed niece
Sruti Saha

DECLARATION

I do hereby declare that this research work is submitted as a thesis entitled "Sedimentology and Hydrogeochemistry of the Tista River, Rangpur Division, Bangladesh" to the Department Geology and Mining, University of Rajshahi, Bangladesh for the degree of Master of Philosophy. This research was carried out myself and was not submitted for any degree or diploma.

Sudip Saha
27.12.2

Sudip Saha

CERTIFICATE

The thesis entitled 'Sedimentology and Hydrogeochemistry of the Tista River, Rangpur Division, Bangladesh' presented by the student embodies the results of investigations carried out by him under our direct supervision and guidance. We certify that this work is original and has not been presented for any other degree or diploma.

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- Saha S., Reza, A.H.M.S. and Roy M.K. (2019) Analysis of Physiochemical Parameters to Evaluate the Water Quality of the Tista-Brahmaputra River, Rangpur Division, Bangladesh. "IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG) 7.4: 27-35.
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- Saha S., Reza, A.H.M.S. and Roy M.K., (2020) Illite crystallinity index an indicator of physical weathering of the Sediments of the Tista River, Rangpur, Bangladesh: International Journal of Advanced Geosciences, 8(1): 27-32. DOI:10.14419/ijag.v8i1.30551
- Saha S., Reza, A.H.M.S. and Roy M.K., (2020) The geological setting of arsenic enrichment in groundwater of the shallow aquifers of the Tista Floodplain, Rangpur, Bangladesh: International Journal of Advanced Geosciences, 8(2): 231-236. DOI: 10.14419/ijag.v8i2.31116

ABSTRACT

The present research work is dealt with the study of sedimentology and hydrogeochemistry of the Tista River and its adjoining area, Rangpur division, Bangladesh. Sediments of the Tista River are composed of the sand particles that are laden with cobbles and pebbles. Percentage of sand towards downstream direction is decreased with respect to increasing fraction of mud. The unimodal distribution of the sediments indicates of single source for the studied sediment samples. About sixty percent of the studied sands are very fine sand. The well sorted nature of the sand is suggestive of effective transporting capacity of the sand particles. The skewness values vary from -0.41 to 0.35 indicating the mixture of both coarse fraction and fine fraction within the sediments. Most of the samples are leptokurtic and 11% are mesokurtic. Plots of mean size and sorting suggest that the sands are hydraulically controlled. Lithofacies matrix supported conglomerate (Gms), massive sand (Sm), trough cross stratified sand (St), planar cross stratified sand (Sp), ripple laminated sand (Sr), parallel laminated sand (Sh), clay with silt (Fl) and massive clay (Fm) were recognized in the exposed lithosuccession of the Tista River. The channel deposits are formed under high energy conditions. The overbank fine sediments are constituted by the facies of Sr, Sh, Fl and Fm covering the uppermost part of the lithosuccession. The finer sediments are the suspension products of floodplains or back swamps

The minerals of illite group are the major clay sized minerals in Tista River deposits with quartz, feldspar, chlorite and kaolinite. The minerals that are found in trace quantities include lavendulan, lepidolite, enstatite, sekaninaite and ferrierite. The low illite crystallinity indices indicate that the mechanically formed illites are well crystallized. The present study shows that the sediments are acidic in nature which reflects that they are derived from acid rocks. The mean EC value of the sediments was 1.16 ds/m that indicates very low or negligible effects of salinity of the sediments. The Recent deposits of the Tista River contain low amounts of total organic carbon. The average concentration of N is 0.0268%. The concentrations of iron vary from 24367.4 mg/kg to 27891mg/kg with the mean concentrations of 26310.77 mg/kg. Sulphur is significantly positively correlated with copper and zinc ($p<0.05$) and insignificantly positively correlated with arsenic content of the sediments that indicates that the copper and zinc occur as sulphide minerals.

The major cations of river water are K and Mg and it has mean TDS value of 99.6 mg/l. From this research, it is revealed that the river water is allowable for irrigation purposes and have low As content.

The groundwater pH, EC and temperature in the study area are within the permissible range. Na is the major cation whereas HCO_3^- and Cl^- are the principal anions. The groundwater samples are suitable for drinking and domestic uses. Potassium exceeds allowable limit in three groundwater samples and this is resulted from the anthropogenic activities. The groundwaters of the investigated area have excellent qualities for irrigation and livestock purposes. Precipitation and rock dissolutions are the main sources of the water of the Tista River and adjoining areas. The arsenic concentrations of groundwater ranged from 0.67μg/l to 1.87μg/l and none of the samples exceeded the maximum permissible limit of 10 μg/l which recommended by WHO. The concentration of arsenic in groundwater positively correlated with the arsenic concentrations of sediments. The coarser rock particles of the Tista River contain low arsenic and release less arsenic to the riverwater and groundwater. The wells are safe considering the arsenic concentrations of groundwater due to elevated topography and remarkably higher hydraulic gradients that result more effective groundwater flushing. 93.33% groundwater samples have higher Mn content than the permissible limit of 0.01 mg/l recommended by WHO.

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The author

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CHAPTER: 1

INTRODUCTION

1.1 General Introduction

Water is a renewable natural resource which is essential for all sort of organisms. The water resource constitutes the central part of the ecosystem (Selvam *et al.* 2013). Many people all over the world are suffering from shortage of safe water supplies.

The water quality is influenced by geogenic and anthropogenic activities like agriculture, industry and urbanization. In unconfined and semi-confined aquifers, the groundwater chemical composition is controlled by the sediments chemistry of the vadoze zone especially in case of the vertical infiltration and the seasonal floods when the all the pores are saturated with the water. The particle size of the aquifer also influences the water quality of a place.

A number of research works were carried out in different parts of the Tista Floodplain of Rangpur Bangladesh by many researchers. Mazumder *et al.* (1994) carried out research on the roundness and sphericity study of the mechanically formed Tista River deposits of Rangpur, Bangladesh. Afroza *et al.* (2009) conducted a detailed work on hydrogeochemistry and salinity of groundwater in the lower part of the Tista Floodplain. The Tista fan deposits age range from Late Pleistocene to Holocene age and are constituted of gray coloured coarse sand, cobbles and gravels that has transmissivity of 3500-7000m^2/day (UNDP, 1982: Hussain and Abdullah, 2001). DPHE- BGS (2001) concluded that the least arsenic affected areas of Bangladesh are Lalmonihat, Nilphamari, Rangpur, Gaibandha and Kurigram. The trace elements of groundwater of Rangpur district was determined by Islam *et al.* (2017). Moni *et al.* (2019) worked on the spatial distribution and hydrochemistry of arsenic in shallow alluvial aquifers of Rajarhat, Kurigram. The hydrochemical characteristics of the aquifers of the Tista River basin and adjoining areas were not addressed by any research work. The water quality of an area should be monitored regularly as any change in the natural equilibrium along with anthropogenic activities like industrialization and agricultural activities can release certain elements to the natural water.

1.2 Objectives of the Research Work

1.2.1 Overall Objectives

Present research work has been taken to decipher the modern sedimentation pattern, major and trace element hydrogeochemistry of water both (Tista riverwater and adjoining areas groundwater) and their correlation with sediments arsenic. The present work is helpful to the people of this area, as it describes the water quality (for domestic, industrial, agricultural purposes), As and Mn content of water and sedimentation pattern of the deposits.

1.2.2 Specified Objectives

The exact objectives of the present work are as follows:

- To analyze the texture of the Tista river sediments,
- To analyze the facies of the sediments as exposed along the river bank and bars,
- To study the mineralogical composition of the finer particles using the XRD analysis and to interpret the dominant type of weathering and the possible source of arsenic bearing minerals,
- To analyze the EDS study of the sediments to show the presence of heavy metals like As, Mn and Fe in the sediments,
- To analyze the sediment chemistry and to decipher their relations to the water chemistry, especially with arsenic,
- To analyze the water chemistry parameters and interpret the data of the water resource
- To determine hydrochemical type of water,
- To determine the quality of water for various uses like domestic, irrigation and livestock purposes.

1.3 Hypothesis of the thesis

The arsenic content of the Tista River sediments is low, hence it is assumed that concentration of arsenic in river water and groundwater is low.

1.4 Thesis Organization

Chapter: 1 describes the introduction of the present research and comprises of general introduction, research objectives, hypothesis of the thesis and thesis organizations.

Chapter: 1 also shows literature review that states the sedimentology and hydrogeochemistry of the river and groundwater of the investigated area.

Chapter: 2 is Geology of the Study Area which is a description of the location, climate, physiography and relief, vegetation, stratigraphic succession of the study area and hydrogeological conditions.

Chapter: 3 describes as data acquisition and it delineates the ways of primary and secondary data acquisition or collection.

Chapter: 3, materials and methods is dealt with the laboratory analyses methods and mathematical and graphic expressions.

Chapter: 4 is known as results and discussion that systematically outlines the findings of the research and their logical interpretation.

Chapter: 5 the final chapter figures out the conclusions and recommendations of the work.

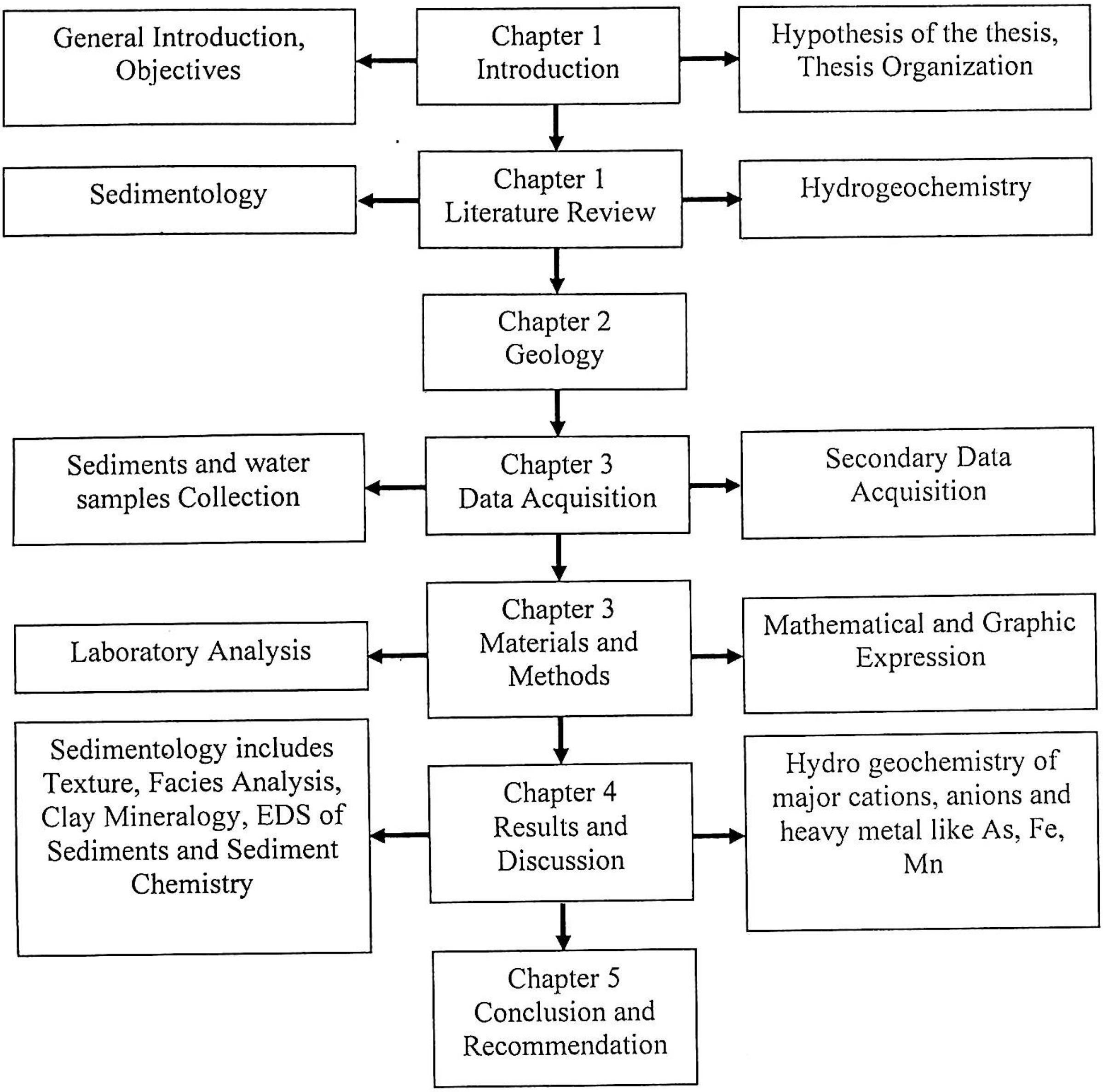

Figure 1.1 Structural View of the Thesis

1.5 LITERATURE REVIEW

1.5.1 Sedimentology

The study of the stratigraphic succession provided by UNDP 1982 and Hossain, 1999 was a key to know about the surface geology and the subsurface rocks of the investigated area. Mazumder *et al.* 1994 summarized that the Tista river clastics are poorly sorted. The research work of Vezolli *et al.* 2017 showed that the sand of the Tista basin is characterized by quartz, feldspar and low-grade metamorphic rocks.

Taral *et al.* 2017 recognized, huge numbers of wave generated structures and marine trace fossils in the sedimentary successions of Siwalik in the Tista Valley in its upper course. The changes in kurtosis values delineate the flow characteristics of the river (Rajganapathi *et al.* 2012; Ray *et al.*, 2006; Baruah *et al.*, 1997). The precipitation, melting glacier and snow and groundwater are major water sources of the Tista river (Mukhopadhyay, 1982).The identifications and interpretations of lithofacies were performed following Miall, 1984; Reading, 1986 and Roy *et al.*, 2001.

The heavy minerals like micas, amphiboles and garnet comprise the sediments of the Tista river basin (Biswas *et al.* 2018). The Recent deposits of the Tista river have high content of SiO_2 (Hossain *et al.* 2013). Most of the sediments of Brahmaputra river are distinguished by the low concentrations of nitrogen (Moslehuddin 1993: Moslehuddin *et al.*, 1997).

1.5.2 Hydrogeochemistry

The trace element chemistry of groundwater of Rangpur area is mainly related to natural/geogenic sources followed by anthropogenic activities (Islam *et al.*, 2017).
The spatial distribution and hydrochemistry of arsenic (As) in shallow alluvial aquifers of of Rajarhat upazilla, Kurigram was carried out by Moni *et al.* 2019 and the research reveals that the aquifers transform from oxidizing to reducing conditions, with increased arsenic concentrations in the groundwater. The lowest arsenic concentrations in shallow groundwater are reported from the Tista and Brahmaputra River floodplains in Bangladesh (DPHE-BGS 2001: Ravenscroft 2001). The TDS values of the groundwater samples in parts of Kurigram district are within the permissible limit of DOE, 1997 (Rahman *et al.* 2012). For water classification piper diagram was used after Piper 1944. The source of groundwater was determined by the application of Gibb's diagram (Gibb 1970).

CHAPTER: 2

GEOLOGY

2.1 Location

The present work is dealt with the Tista river and its adjoining areas, that is situated in the parts of in the Nilphamari, Lalmonirhat, Rangpur, Gaibandha and Kurigram districts of Rangpur division, Bangladesh. The investigated area is bounded by the latitude 25°34'22"N to 26°11'45"N and the longitude 88°59'4"E to 89°40'28"E.

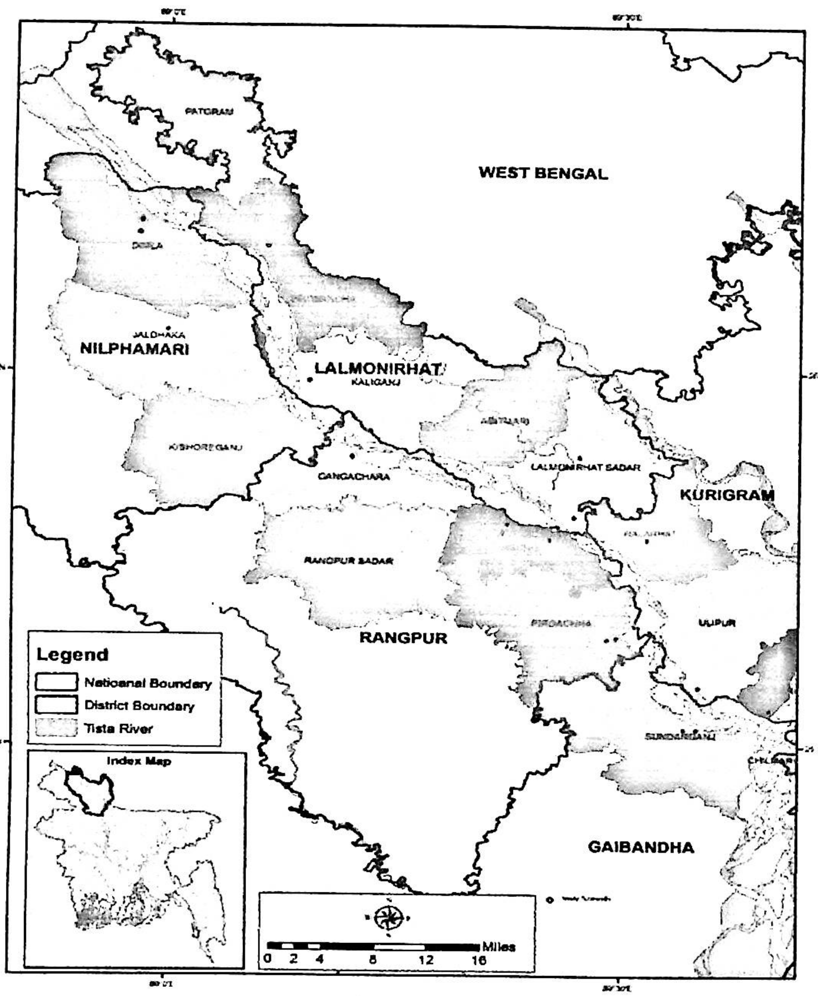

Figure 2.1: Location map of the Tista river and its surrounding areas (after Saha *et al.* 2019).

CHAPTER: 2

GEOLOGY

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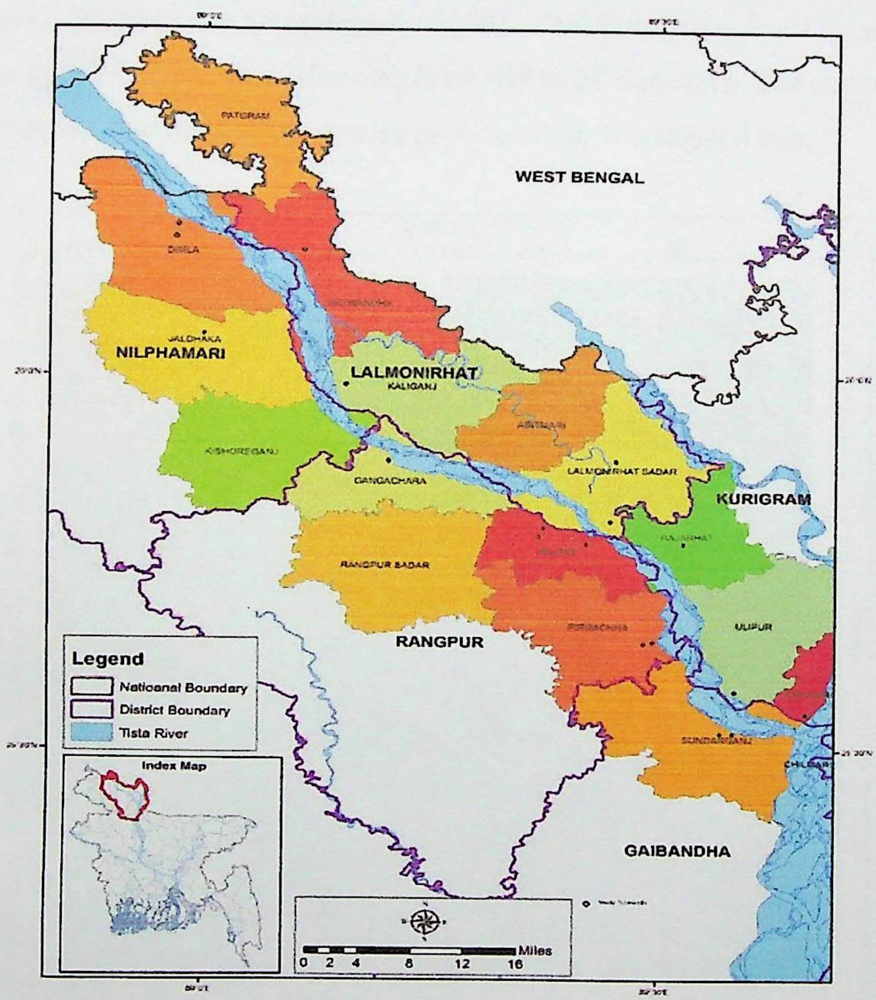


Figure 2.1: Location map of the Tista river and its surrounding areas (after Saha *et al.* 2019).

2.2 Climate

Heavy monsoon rainfall is a characteristic feature of Rangpur division (Islam *et al.* 2017). The summer temperature varies from 32°C to 36°C while the temperature is recorded as 7°C to 16°C in the winter months (Banglapedia 2006). The average rainfall is recorded slightly over than 1900 mm in the Tista floodplain regions (Banglapedia 2006).

2.3 Physiography and Relief

The Tista river is bounded by the Tista floodplain. The Tista floodplain extends to the Himalayan piedmont plain to the west whereas the eastern portion merges with the floodplains of the mighty Brahmaputra (Banglapedia 2006). The Tista river itself is an example of geomorphic unit. The Tista river is flowing from NW to SE directions. The contour map shows that the elevations decreases to the eastern portion of the investigated area.

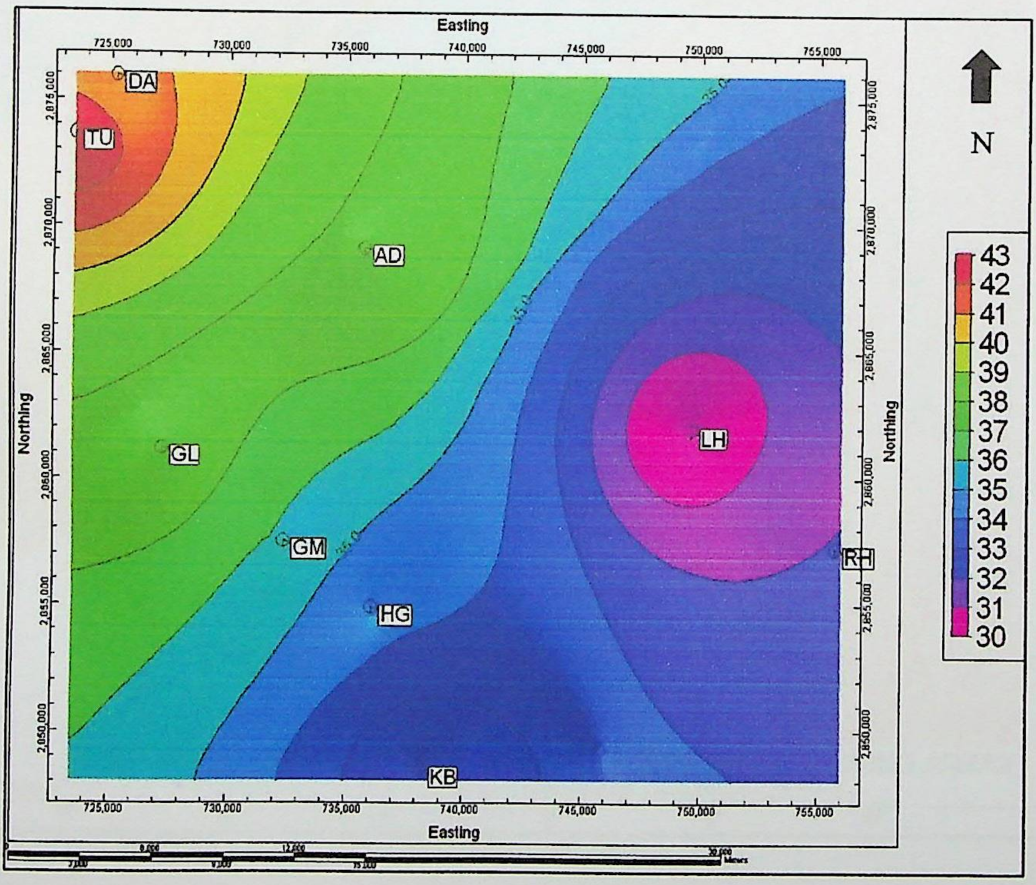


Figure 2.2: Elevation map of the study area (contours in meter) (after DPHE-JICA, 2010).

The Tista is a straight river and it is fault bounded (Sarker *et al.* 2009). The river behaves like a braided river in its lower course due to construction of different engineering structures. Tectonically, the area is in Rangpur saddle (Figure 3.3).

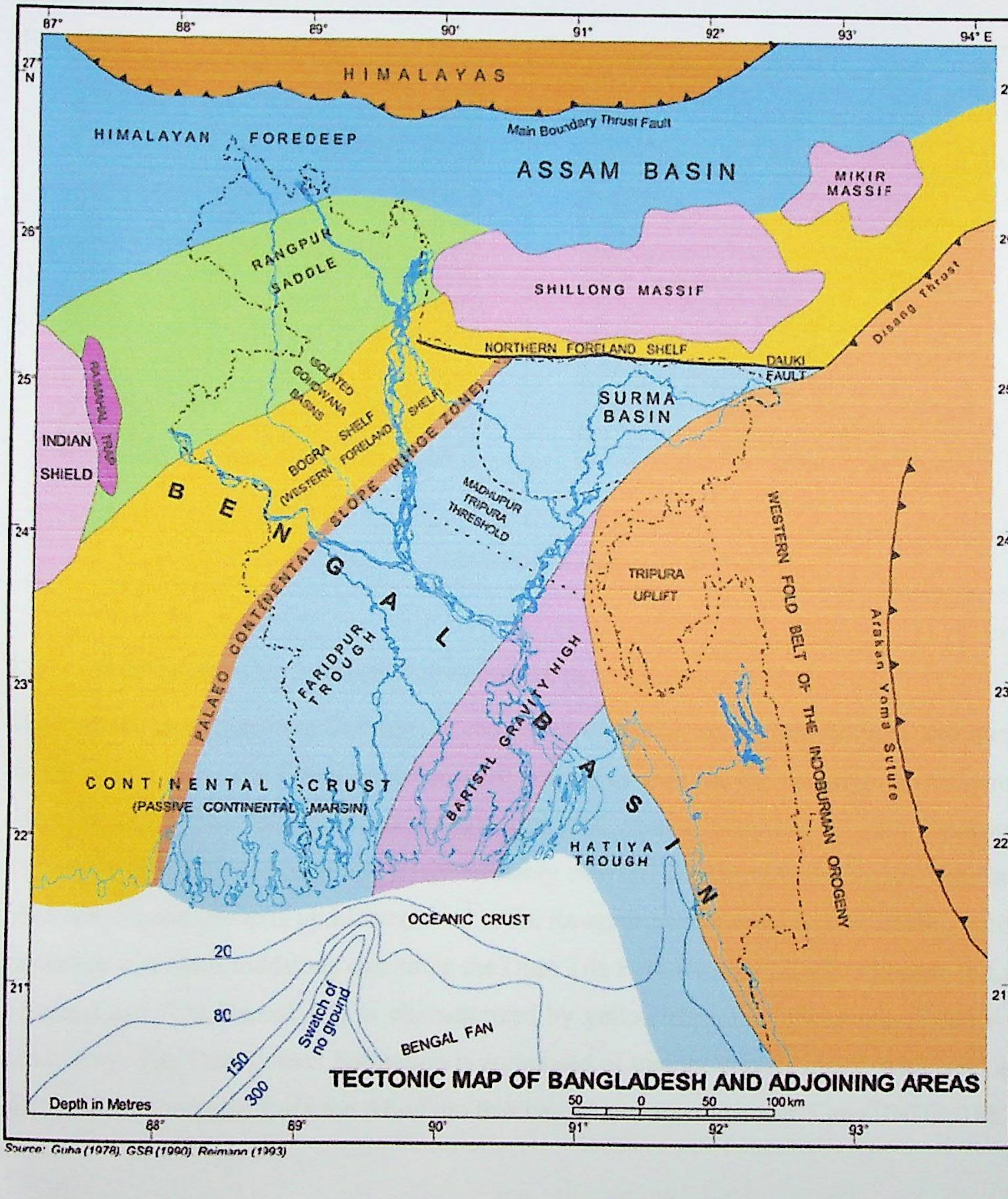


Figure 2.3: Geo-tectonic Map of Bangladesh and Adjoining Areas (Reimann, 1993).

2.4 Vegetation

Rangpur is green with abundant varieties of trees namely, mango, jack fruit, banana, coconut, betel-nut, shaal etc. Different types of crops like rice, wheat, potato, maize (Figure 3.4) etc. grow all the year round.

a. Potato

b. Maize

Figure 2.4: Potato and maize cultivation.

2.5 Stratigraphic Succession of the study area

The Precambrian Basement Complex is composed of gneiss, schist, granodiorite and quartz diorite (Table 3.1). The Gondwana Group of sediments overlies the Precambrian Basement complex and shale, feldspathic sandstone and coal seams comprise it. Tura Sandstone Formation of Middle Eocene age unconformably overlies the Gondwana Group. The Early Miocene, Surma Group is undifferentiated in the Rangpur Saddle area (UNDP, 1982). Pebbly sandstone and shale/mudstone constitute the Dupi Tila Formation of Middle Pliocene to Late Miocene age. The Barind clay is characterized by yellowish brown sticky clay laden with sandy clay. The Tista Gravel Formation is composed of mainly gravels mixed with sand and silt. Sand, silt and clay form the Alluvium that has an average thickness 53m (UNDP, 1982).

Table 3.1: Stratigraphic succession of the Rangpur Saddle, Bangladesh (Modified after Hossain, 1999 and UNDP, 1982)			
Age	**Group/Formation**	**Lithology**	**Thickness**
Recent to Sub-Recent	Alluvium	Sand, silt and clay	53m.
Late Pleistocene-Holocene	Tista Gravel	Gravels with sand and silt	89 to 97m
Pleistocene	Barind Clay Residuum	Yellow-brown sticky clay and sandy clay,	15m
Middle Pliocene to Late Miocene	Dupi Tila Formation	Sandstone and shale/claystone with pebbles.	171m.
Early Miocene	Surma Group undifferentiated (?)	Sandstone, siltstone and shale.	125m.
Middle Eocene	Tura Sandstone (?) Formation	Grayish white sandstone with subordinate greenish gray shale and coal.	128m.
Late Permian	Gondwana Group	Feldspathic sandstone, shale, coal beds	475m.
Precambrian	Basement complex	Gneiss, schist, granodiorite, quartz diorite	

2.6 Hydrogeological Setting of the study area

The aquifers of the area under investigation are composed of coarser deposits. These have the highest transmissivity in Bangladesh that range from 1000-7000 square meters/day (Hussain and Abdullah 2001; UNDP 1982). The Tista river and its floodplain is underlain by aquifers that comprised of fine, medium and coarse sands with a higher proportion of silt and clay with average thickness of 2 meters. The thickness of aquifers varies from 5-50 meters with average thickness of 20 meters (Hussain and Abdullah 2001). Occasionally, the aquifers contain clay lenses. The aquifer of the study area is mainly unconfined and in some places semi-confined. Medium to coarse sand, coarse sand and sandy gravel comprise the aquifers. Silt and sandy clay constitute the aquitard and aquiclude (Figure 3.5).

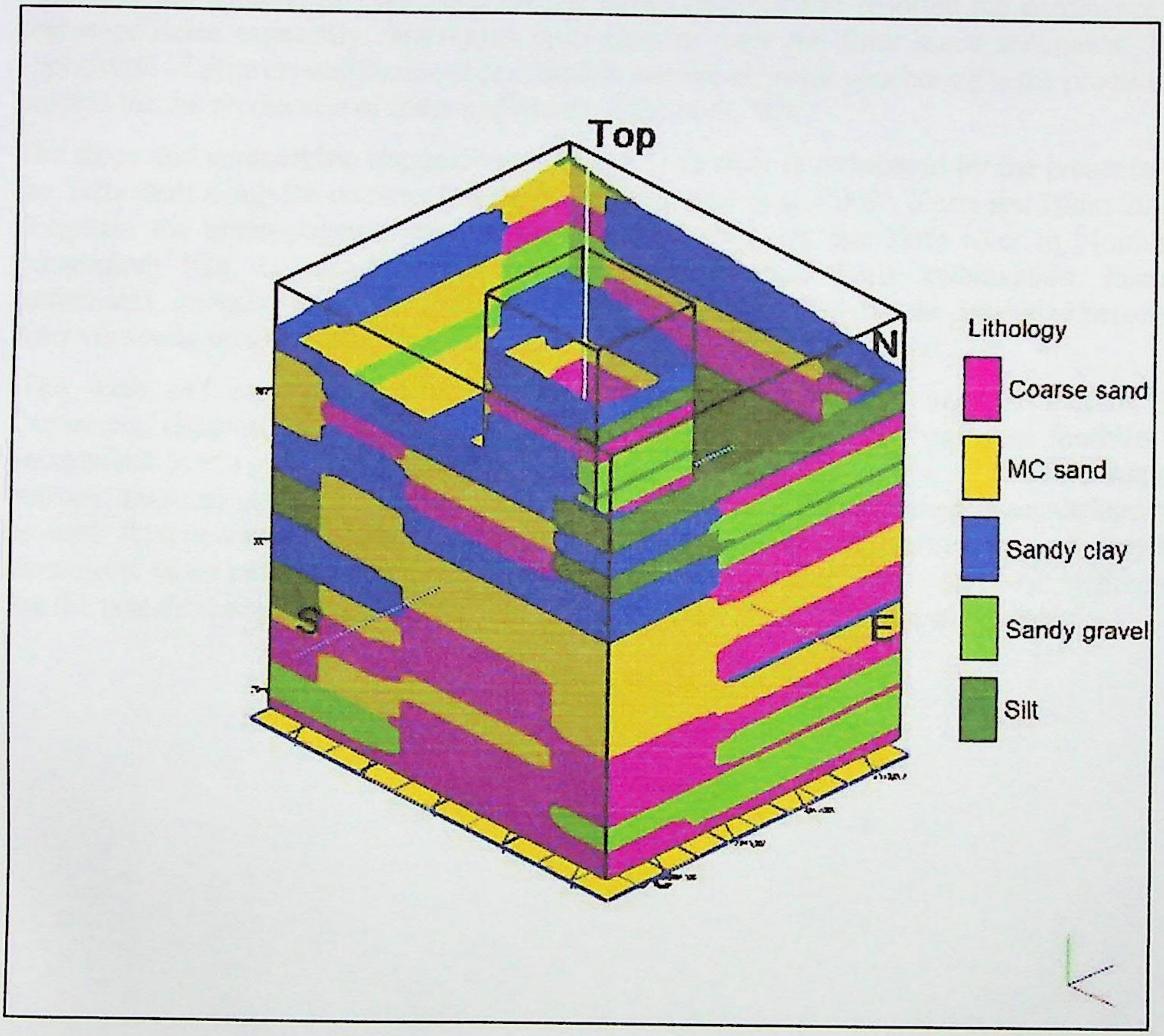


Figure 3.5: Concentric Panel Diagram of aquifer, Rangpur (after DPHE-JICA, 2010).

2.7 Geology and Geomorphology

The Tista is a fast-flowing river and fed by the rainfall, glacial melt and groundwater flow. It emanated from the Himalayan Mountain Range and running through India and Bangladesh (Chakraborty and Ghosh 2010). The landslides are a common incident in the mountainous part of the basin whereas the basin is inundated with seasonal flood events in its lower course in the plain lands (Pal *et al.* 2016). The river, floodplains, medial bars and side bars comprise the major geomorphic regions of the study area.

The petrographic of analysis of Tista fan sandstone reveals the dominance quartz, feldspar and mica (Akter *et al.* 2003). Chakraborty and Ghosh 2010 worked on the geomorphology and sedimentology of the Tista megafan in Darjeeling Himalaya and concluded the advancement of the paleochannels southwestward after analyzing the paleocurrents data. Chakraborty *et al.* 2018 studied the subsurface lithofacies and they identified seven different lithofacies of fluvial origin in West Bengal, India. Saha *et. al.* 2017 worked on the textural aspects of the deposits as exposed along the banks and bars and reported the dominance of coarse particles especially sand laden with pebbles over the finer sized sediments. The application of illite crystallization index implies that the physical weathering is the prominent process for the production of these sediments (Saha *et al.*2020).

The slope and geomorphic characteristics of the Tista river is influenced by the presence of the Tista fault along the course of the Tista river (Sarker et al. 2009). Khan and Islam 2015, deciphers the anthropogenic impacts on the morphology of the Tista river in Northern Bangladesh like the construction of bridges and barrage, bank stabilization, human settlements, intensive agriculture and sand mining. It was reported that the grain size becomes finer vertically upwards and along the downward course of the Tista river.

The wide and rapid spectral variations in sedimentary structures and textures in the Quaternary deposits on the banks of the mighty river Teesta at the Himalayan foothills in Bangladesh bear a snapshot of an extremely unstable depositional regime. The sedimentation entropy involved is further manifested in biogenic responses that include human settlements as well. Recent additions of bridges, barrages, dams, sand mining, cultivation and channel diversions cause modifications of the primary attributes of the deposits. Miocene sediments are the principal source of the deposits of the Quaternary deposits of the study area.

CHAPTER: 3
MATERIALS AND METHODS

3.1 Field work and field data collection

Extensive field works were carried out along the bank cliff and bar sections of the Tista river sediments and for the measurements of the in-situ parameters and the collection of sediment samples and water samples in 2014.

3.1.1 In-situ measurements

In the field, the sediments were categorized as gravels, pebbles, sand, silt and clay on the basis of their grain size. The colour of the sediments is one of the useful tool to characterize the deposits. The thickness and dip of each sediment bed was measured in the field. The sedimentary structures were studied and lithologs were drawn in the field. Necessary photographs were also taken.

The EC, pH and temperature of the water samples were measured in situ after pumping the tube-well for 10 minutes and recorded.

3.1.2 Sediment Sample Collection

The sediment samples were taken for textural analysis, clay mineralogical and geochemical study. 500 grams' sediments were collected from each sampling location in polythene bags following the standard sampling procedure. The samples were labeled properly and taken to the laboratory for analysis.

3.1.3 Water Sample Collection

The water samples were collected in polythene bottles, after pumping continuously for 10 to15 minutes until the temperature, electrical conductivity (EC) and pH reading reached at a definite point. To determine the chemical composition 100 mL polythene two sample bottles were filled with water from each location. The colloidal and suspended materials were removed by filtering. To perform the analysis of cations, ten to twelve drops of ultrapure nitric acid (HNO_3) were mixed in one of the bottle of water for preservation.

3.2 Secondary Data Acquisition

The secondary data of the study area of Rangpur division of Bangladesh were collected from different maps (like Geological map, Temperature map, Tectonic map etc.), grain size, mineralogical data, water quality data of previous years were collected from the different organizations and different reports and books and cited properly when those used.

3.3 Laboratory Analysis

3.3.1 Laboratory Analysis of Sediments

3.3.1.1 Textural Analysis

The grain sizes of 26 sediment samples were determined in the laboratory following standard methods. The materials and instruments used for the laboratory analysis are: a) balance, b) sieve mesh openings, c) thermostatically controlled oven, d) trays, e) sieve brushes, f) mortars with rubber cover pestle and g) Tyler Ro—Tap resting sieve shaker. Sediment samples were kept in an oven dryer for duration of one day at 100°C and then cooled to 25°C (Mazumder *et al.,* 1994). 100 grams of each of the samples weighed using a balance. The samples were then sieved. Each of the samples was sieved for 15 minutes and grains retained on each sieve were weighed.

3.3.1.2 Facies Analysis

The Sedimentary deposits are examined along the vertical cliffs sections and medial bar throughout the Tista river in Rangpur division from upstream to downstream direction. The deposits were examined and logged in details to decipher spatial variations from February to June in 2014. The average thickness the studied sections were around 1.34 m. The exposed sediments assigned to number of distinct facies. Facies identifications and interpretations were based on detailed examination of colour, texture, composition, sedimentary structures and bedding characteristics (Miall, 1984; Reading, 1986; Roy *et al.* 2001). The lithologs were drawn using a computer software, Sedlog 3.0.

3.3.1.3 Clay Mineralogy

The study of clay minerals was done following the methodologies as given by Heroy *et al.* (2003) and Tennant (2005). The mineralogical composition of the total sediments and clay fractions (<2μm size) were determined. The gravity settling and wet sieving techniques were employed for the separation of clays. The clay samples were scanned by Rigaku X-ray diffractometer (XRD) with Cu-Kα radiation in three states in order to best differentiate between various peaks of the minerals like air dried, ethylene glycol solvated and solvated with dimethyl sulphoxide (DMSO). Peaks were calculated with the application of required software. The relative abundances of minerals were determined following Biscayes, 1965 method. Illite crystallinity was formulated using the method of Kübler as described by Jaboyedoff *et al.* (2001).

3.3.1.4 EDS analysis of the Sediments

The sediment samples were mounted on double sided tape. The element chemistry analyzed using the attached EDS. (FSSEM (model JSM 7600F, JEOL-Japan). The equipment is also attached with EDS which is capable of elemental identification and mapping.

3.3.1.5 Geochemistry of the Sediments

Ten grams of dry sediment sample was taken into a 100 ml beaker and mixed with 20 ml of distilled water. The mixture was stirred for 10 minutes on a reciprocal shaker, left to stand for 30 minutes and shaken for 2 minutes. The pH value of the suspension was measured. For the determination of EC of sediments, the suspension of ten grams of sediments was prepared with 50ml of distilled water. The S content in the sediments were measured by turbidimetric method as described by Subba Rao, 1993, while the total organic carbon for the sediments is determined by wet oxidation (Schumacher, 2002). Kjeldhal digestion method was employed for the determination of total nitrogen in sediments (Black 1965).

The Cu, As, Fe and Zn content of sediments were analyzed. The dried sediments were dissolved in aqua-regia following the procedures of Sakala *et al.* 2011. For the analyses the filtrates were stored in plastic bottles and the analyses for arsenic was performed by an AAS attached with a graphite furnace (Shimadzu, AA6800).

3.3.2 Laboratory Analyses of Water

Na and K concentrations of river water and groundwater were determined by flame photometer (Afroza *et al.* 2009). An atomic absorption spectrometer was used to determine the Ca, Mg and heavy metals for river waters and groundwaters. Cl^- was measured by

Argentometric method using standard $AgNO_3$ solution while HCO_3^- was determined with titration with hydrochloric acid. UV-visible spectrophotometer was used for the determination of SO_4^{2-} in groundwater and river waters.

3.4 Mathematical and Graphic Expressions

3.4.1 Mathematical and Graphic Expressions of the Sediments

From these graphical plots, statistical size frequency parameters like mean size, sorting and graphic kurtosis were calculated using percentile values. The graphs were constructed to reveal relationship between the mean grain size and sorting, sorting and skewness, skewness and kurtosis using Microsoft Excel Software. The lithologs were drawn using a computer software, Sedlog 3.0. Illite crystallinity was calculated following the method of Kübler described in Jaboyedoff *et al.* (2001).

3.4.2 Mathematical and Graphic Expressions of the Water Samples

Total Hardness (TH) of the water samples were calculated by using the formula as given by Raghunath, 1987 and Sawyer *et al.* 2003:

$$\text{TH in mg/l} = (Ca^{+} + Mg^{+}) \times 50$$

where all the concentrations are in meq/l.

Residual Sodium Carbonate (RSC) of the water was estimated by the formula (Eaton 1950; Raghunath 1987):

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{+} + Mg^{+})$$

where all the concentrations are in meq/l.

Permeability Index (PI) was computed using equation developed Doneen 1964 and Raghunath 1987:

$$PI = \frac{Na + \sqrt{HCO3}}{Ca + Mg + Na} \times 100$$

where all the concentrations are in meq/l.

The Sodium Adsorption Ratio was estimated by using the formula formulated by Richards 1954:

$$SAR = \frac{Na}{\sqrt{Ca + Mg/2}}$$

where all the concentrations are in meq/l.

Soluble Sodium Percentage (SSP) of water was computed using the equation given by Todd 1980:

$$SSP=\frac{(Na+K)\times 100}{(Ca+Na+Mg+K)}$$

where all the concentrations are expressed in meq/l.

Magnesium Hazard (MH) was calculated by the following the equation developed by Szabolcs and Darab 1964 for irrigation use of water:

$$MH=\frac{Mg\times 100}{Mg+Ca}$$

where all the concentrations are expressed in meq/l.

CHAPTER: 4

RESULTS AND DISCUSSION

4.1 Sedimentology

4.1.1 Textural Analysis

The histogram and cumulative frequency curves were drawn using the statistical data acquired from the grain size analysis of twenty-six sediment samples. From these graphical plots, statistical size frequency parameters like mean size, sorting and graphic kurtosis were determined by using percentile values presented in table 4.1.

Most of the sediments are unimodal that reveal the sands were originated from a single source (Figure 4.1).

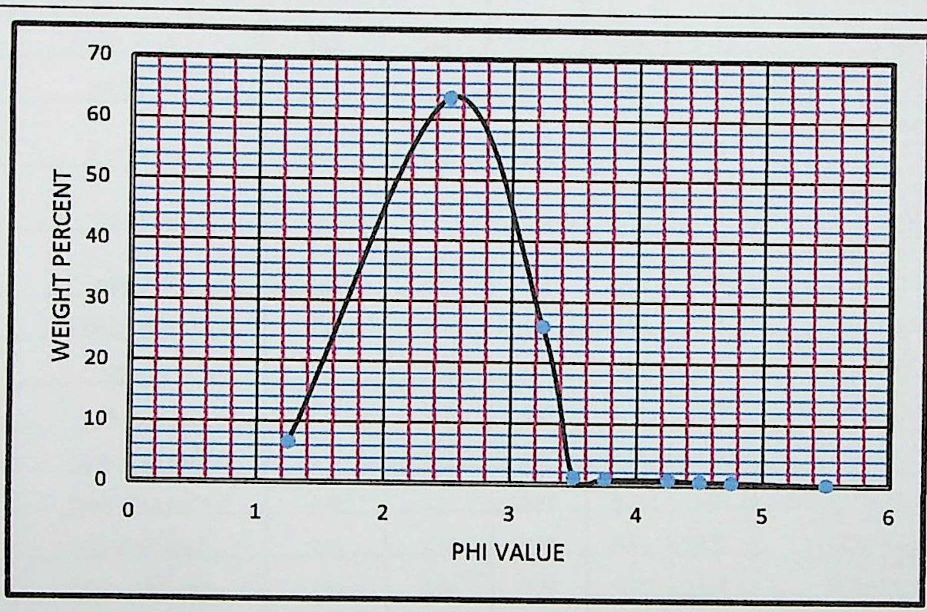


Figure 4.1 Frequency curve of the Tista river sediments

Table 4.1: The results of grain size analysis and its interpretation

Sample No.	LOCATION	MEDIAN Md	MEAN M	S	SK	KG	INTERPRETATION
GS-1	DIMLA	1.05	0.95	1.63	-0.32	1.16	COARSE SAND, POORLY SORTED, VERY COARSE SKEWED AND LEPTOKURTIC
GS-2	KHUNIA GACHH	2.40	2.43	0.46	0.07	1.41	FINE SAND, WELL SORTED, NEAR SYMMETRICAL AND LEPTOKURTIC
GS-3	KAUNIA	3.00	2.92	0.55	-0.14	1.59	FINE SAND, MODERATELY WELL SORTED, COARSE SKEWED AND VERY LEPTOKURTIC
GS-4	GANGACHARA	2.80	2.79	0.64	0.02	1.15	FINE SAND, MODERATELY WELL SORTED, NEAR SYMMETRICAL AND LEPTOKURTIC
GS-5	KALIGONJ	2.28	2.23	0.55	-0.12	1.58	FINE SAND, MODERATELY WELL SORTED, COARSE SKEWED AND VERY LEPTOKURTIC
GS-6	KHUNIAGACHH	2.95	2.90	0.41	-0.09	1.33	FINE SAND, WELL SORTED, NEAR SYMMETRICAL AND LEPTOKURTIC
GS-7	SUNDARGONJ	3.10	3.08	0.62	-0.01	2.29	VERY FINE SAND, MODERATELY WELL SORTED, NEAR SYMMETRICAL AND VERY LEPTOKURTIC
GS-8	HATIBANDHA	2.28	2.21	0.69	-0.06	1.77	FINE SAND, WELL SORTED, NEAR SYMMETRICAL AND VERY LEPTOKURTIC
GS-9	RAM LALMONIHAT	2.80	2.77	0.44	-0.21	0.90	FINE SAND, WELL SORTED, COARSE SKEWED AND MESOKURTIC
GS-10	PIRGACHA	3.10	3.08	0.55	0.01	1.83	VERY FINE SAND, MODERATELY WELL SORTED, NEAR SYMMETRICAL AND VERY LEPTOKURTIC
GS-11	CHILMARI	3.65	3.62	0.66	-0.10	1.17	VERY FINE SAND, MODERATELY WELL SORTED, NEAR SYMMETRICAL AND LEPTOKURTIC
GS-12	PIRGACHA	2.65	2.67	0.53	0.01	1.02	FINE SAND, MODERATELY WELL SORTED, NEAR SYMMETRICAL AND MESOKURTIC
GS-13	CHILMARI	2.32	2.29	0.52	0.00	1.68	FINE SAND, MODERATELY WELL SORTED, NEAR SYMMETRICAL AND VERY LEPTOKURTIC
GS-14	HARIPUR	3.20	3.27	0.52	0.18	1.84	VERY FINE SAND, MODERATELY WELL SORTED, FINE SKEWED AND VERY LEPTOKURTIC
GS-15	MOHIPUR	3.35	3.52	0.60	0.35	1.04	VERY FINE SAND, MODERATELY WELL SORTED, VERY FINE SKEWED AND MESOKURTIC
GS-16	US TISTA BARRAGE	2.10	2.03	1.15	-0.06	1.41	MEDIUM SAND, POORLY SORTED, NEAR SYMMETRICAL AND LEPTOKURTIC
GS-17	DIMLA	2.08	1.71	1.66	-0.41	1.18	MEDIUM SAND, POORLY SORTED, VERY COARSE SKEWED AND LEPTOKURTIC
GS-18	BAZRA	2.08	1.73	1.67	-0.41	1.17	MEDIUM SAND, POORLY SORTED, VERY COARSE SKEWED AND LEPTOKURTIC
GS-19	DALIA BAZAR	2.70	2.71	0.62	0.13	1.31	FINE SAND, MODERATELY WELL SORTED, FINE SKEWED AND LEPTOKURTIC
GS-20	PIRGACHA MSW	3.14	3.15	0.49	-0.01	2.08	VERY FINE SAND, WELL SORTED, NEAR SYMMETRICAL AND VERY LEPTOKURTIC
GS-21	SUNDARGONJ	2.80	2.78	0.45	-0.01	0.95	FINE SAND, WELL SORTED, NEAR SYMMETRICAL AND MESOKURTIC
GS-22	MARAIYERHAT	2.80	2.84	0.74	0.19	1.38	FINE SAND, MODERATELY SORTED, FINE SKEWED AND LEPTOKURTIC
GS-23	MARAIYERHAT	2.60	2.60	0.61	0.05	1.20	FINE SAND, MODERATELY WELL SORTED, NEAR SYMMETRICAL AND LEPTOKURTIC
GS-24	GANGACHARA	2.05	1.88	0.86	-0.34	1.39	MEDIUM SAND, MODERATELY SORTED, VERY COARSE SKEWED AND LEPTOKURTIC
GS-25	DIMLA	2.30	2.22	0.58	-0.19	1.27	FINE SAND, MODERATELY WELL SORTED, COARSE SKEWED AND LEPTOKURTIC
GS-26	DOAHNI	1.95	1.78	0.74	-0.41	1.18	MEDIUM SAND, MODERATELY SORTED, VERY COARSE SKEWED AND LEPTOKURTIC

Figure 4.2 shows that the amount of mud is increasing to the downstream direction of the Tista river basin.

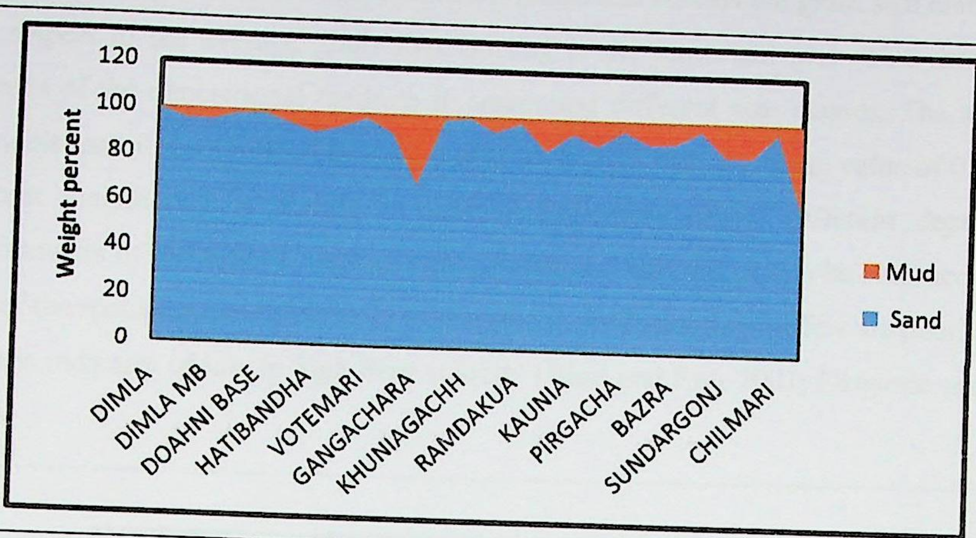


Figure 4.2: Distribution of sand and mud of the Study Area

4.1.1.1 Mean Size

The graphic mean distribution for the studied sediments fluctuates from 0.95 to 3.62φ. The grain size results from the study area reflects that the grain size changes with increasing distances from the upstream direction. The sediments from the upstream area are coarse to medium sand while those of from the downstream area are fine to very fine sand (Figure 4.3). The sands are sometimes laden with the coarser rock particles mostly with cobbles and pebbles of different rock fragments. This indicates that the depositional environment of sediments was under high energy conditions.

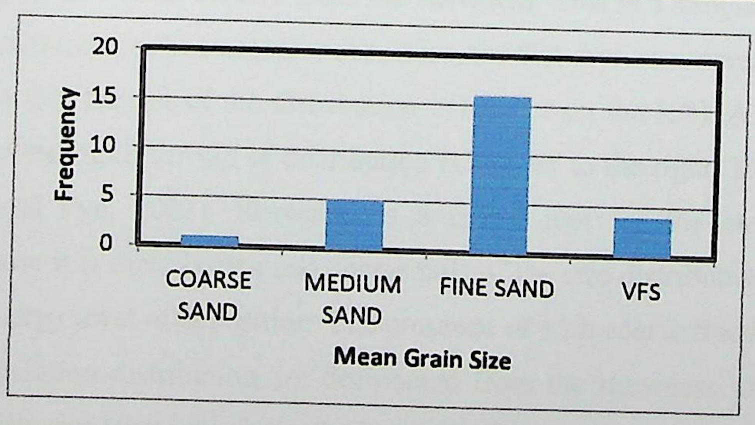


Figure 4.3: Mean grain size distribution of the Tista river sediments of the study area

4.1.1.2 Sorting

Sorting is a measurement of the standard deviation that reveals the grain size distribution with respect to the average grain size. Sorting is the important grain size data which indicates of the depositional medium in separating different size classes. The analyzed sediments manifest a standard deviation of 0.41 to 1.67 with the mean value of 0.73. The different magnitudes of sorting in sand is indicative of the different depositional environments of the sand (Friedman, 1961a). From Table 4.1, it can be summed up that most of the specimen are moderately well sorted to well sorted while few are poorly sorted which is indicates of low to high flow velocity (Blott and Pye, 2001; Okeyode and Jibiri, 2013).

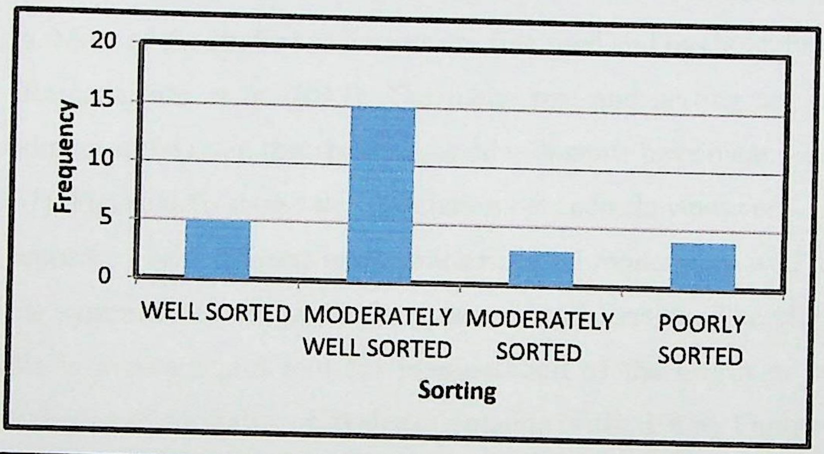


Figure 4.4: The distribution of sorting in the Tista river sediments of Rangpur.

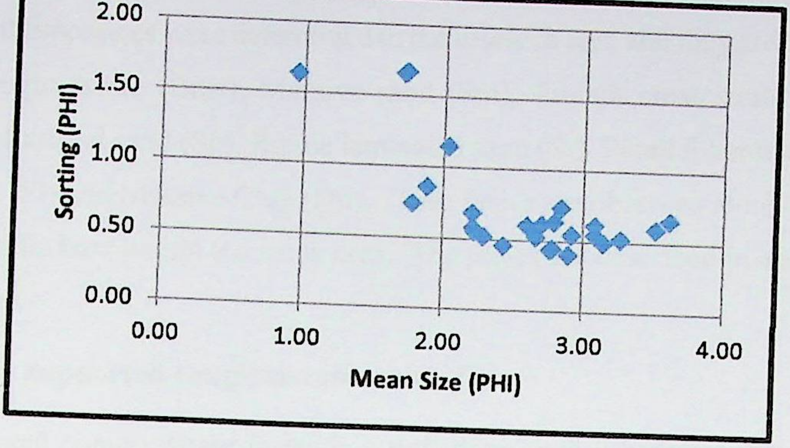
4.1.1.3 Skewness

The depositional process is best studied from the skewness. This is a simple standard of the symmetry the distribution. In a negative skewness, the distribution is spread out to the left (which implies that the tail of the distribution is heavier on the left). A distribution which is skewed to the right (the tail of distribution is heavier to the right) has a positive skewness (Blott and Pye, 2001). Skewness is a useful tool for the environmental identification because it is directly fine and coarse tails of the size distribution and hence indicative of the energy level of deposition. The presence of both coarse fraction and fine fraction in the population distribution are deciphered from the skewness values of the sediments of the Tista river that vary from -0.41 to 0.35. The positive magnitudes indicate skewness towards the finer grain size whereas the negative values showing skewness towards the coarser grain sizes. Sixty-one percent of the samples have negative skewness values reflecting the dominance of the coarser size.

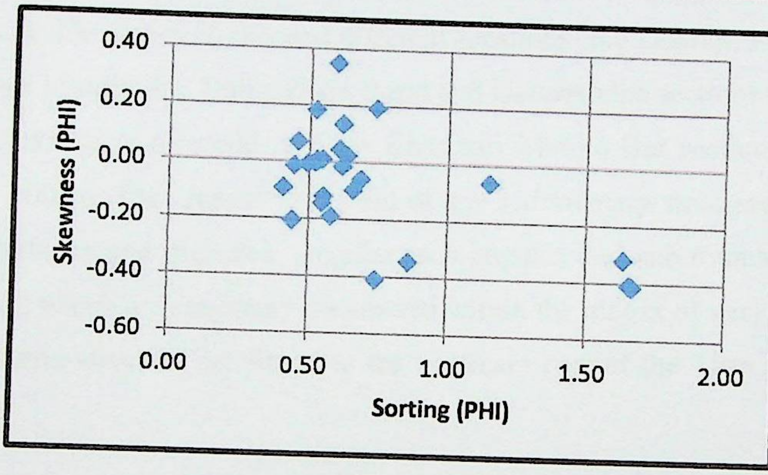
4.1.1.4 Kurtosis

Kurtosis is a measurement of the peakedness of the curve towards the coarser fractions. The sediments are leptokurtic, which describes that the middle portions of the distributions are better sorted towards the tail. The kurtosis values ranged between 0.90 and 2.29. The fluctuation in the kurtosis value reveals of the flow characteristics of the depositing agents (Rajganapathi *et al.*, 2012; Ray *et al.*, 2006; Rajganapathi *et al.* 2012). 65% of the specimens are labeled as leptokurtic, 24% are very leptokurtic and 11% are mesokurtic. This suggests the fluvial environment and ensures that the sands are river deposited.

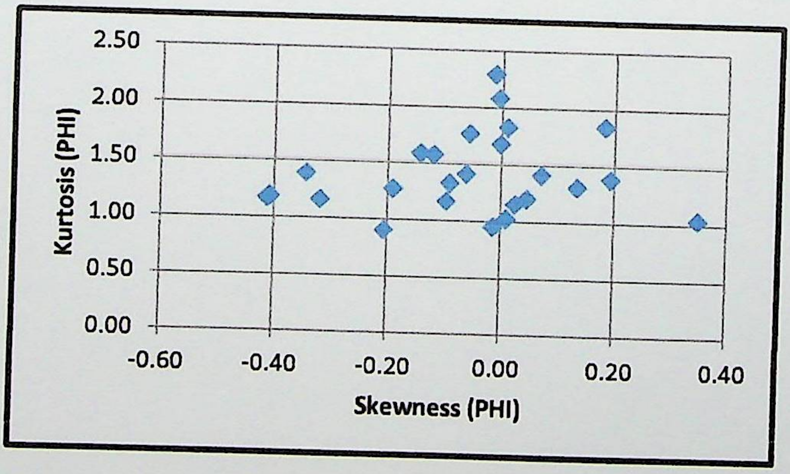
The correlation of the mean grain size and sorting for the Tista River sediments are shown by Figure 6.5a. Most of the studied sediments are fine sand and moderately well sorted to well sorted (Rajganapathi *et al.* 2012). The mean size and sorting are influenced by hydraulic condition of the river, that the best sorted sediments have mean size of fine sand (Griffths, 1967). Figure 6.5b shows the association between skewness and sorting for the Tista River deposits. The sediments are characterized by moderately well sorted to well sorted and near symmetrical natures in fine grained sand fraction. The plot of skewness versus kurtosis is a meaningful tool for interpretation of the origin of sediments, by measuring the degree of normality of its size orientation (Folk, 1966). Figure 6.5c displays that the sediments of the Tista River are within the negatively skewed/mesokurtic to very leptokurtic range which reveals the small proportion of coarse particles and medium sized particles and finer particles provide the positive skewness (Rajganapathi *et al.* 2012).



a) Mean size vs Sorting



b) Sorting vs Skewness



c) Skewness vs Kurtosis

Figure 4.5 Sector plot showing the bivariate relationships

4.1.2 Lithofacies Analysis

Eight different lithofacies were determined in the research area and they are namely Matrix supported conglomerate (Gms), Massive sand (Sm), Trough cross stratified sand (St), Planar cross stratified sand (Sp), Ripple laminated sand (Sr), Parallel laminated sand (Sh), Clay with silt (Fl) and Massive Clay (Fm). These facies are observed along the river bank and in the middle bars within the study area. The facies are described in accordance with their grain size.

4.1.2.1 Matrix supported conglomerate facies, Gms

Matrix supported conglomerate facies is a well-developed lithofacies that occurs at the base of the lithocolumn in the study area. The facies thickness ranges from 10 cm to 100 cm (Table 4.2). The facies is exposed different locations like Doahni, Khuniagachh Bar, Tapa Kharibari Middle Bar, Dalia, Dalia Bazar and Dahabandha sections (Figure 6.6). The maximum thickness is recorded in Tapa Kharibari Middle Bar section and which was measured as 100cm. This deposit is devoid of any sedimentary structures and composed of cobbles, pebbles and granules. Angular, sub-angular and sub-rounded clasts are the most dominant which are randomly distributed within the matrix of very coarse to coarse sand. The coarser deposits are found in the upstream part of the Tista River within the study area.

Table 4.2: Lithofacies Scheme of Tista River sediments, Rangpur, Bangladesh

Facies Code	Lithofacies	Sedimentary structure	Thickness	Interpretation
Gms	Matrix supported conglomerate	None	10-100 cm	Debris flow deposit
Sm	Massive sand	Massive	5-50 cm	Rapid deposition from fluidized flow
St	Trough cross stratified sand	Grouped trough cross bedding	20-60 cm	Dunes (lower flow regime)
Sp	Planar cross stratified sand	Grouped planar cross bedded	20 cm	Two-dimensional bed form, sand waves, linguid and transverse bars.
Sr	Ripple laminated sand	Ripple marks or ripple laminations	5-45cm	Ripple, current generated
Sh	Parallel laminated sand	Horizontal or flat bedding	10-80 cm	Lower flow regime plane bed
Fl	Clay with silt	Ripple laminated	5-50 cm	Over bank/waning flood deposit
Fm	Clay	Massive	5-30 cm	Non channelized swamp deposit

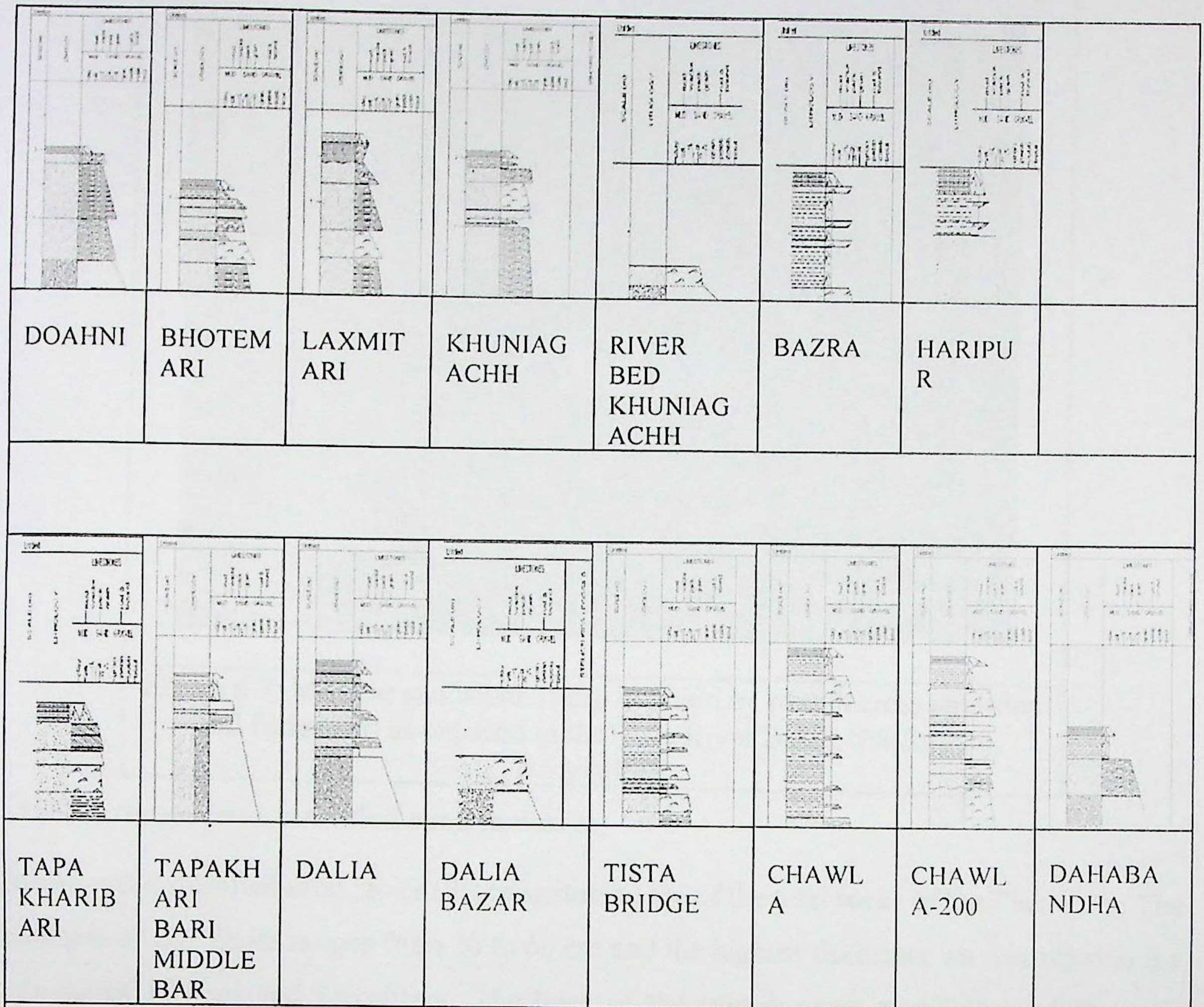


FIGURE 4.6: SEDIMENTOLOGICAL LITHOLOGS OF THE TISTA RIVER BASIN, RANGPUR, BANGLADESH

4.1.2.2 Massive sand facies, Sm

The massive sand facies, Sm consists of fine to very coarse grained, feldspathic sands. The thickness of the facies range from 5 cm to 50cm and the maximum thickness is found at Haripur section (Figure 6.7). The sand colour varies from steel gray to brownish gray. The sand grains are sub-rounded to angular and poorly to moderately sorted. Scattered pebbles ranging from 1cm to 2cm in diameter are present at some locations. This facies is unconsolidated and does not have any sedimentary structure or any fossil content.

Figure 6.7: Massive sandstone (Sm), overlain by trough cross stratified sand facies (St) as exposed in the Tista River Basin, Sundarganj, Bangladesh.

4.1.2.3 Trough cross stratified sand facies, St

Trough cross stratified sand facies (St) constitutes 11% of the total rocks of the Tista river. The thickness of this facies ranges from 20 to 60 cm and the highest thickness was recorded at the sections of Doahni and Laxmitary. The base of the trough cross stratified sand facies is gradational to sharp. The grain size range from very coarse to medium sand and sand is grayish white in colour. St comprises mainly well sorted to moderately sorted and sub-rounded to rounded grains of quartz in association with micas.

4.1.2.4 Planar cross stratified sand facies, Sp

Planar cross stratified sand facies (Sp) is found at Tapa Kharibari of Nilphamari district and the thickness of the bed is 20 cm. The planar cross stratified sand overlies on massive sand (Sm) with a sharp base. The facies composed of fine sand and very coarse sand.

4.1.2.5 Ripple laminated sand facies, Sr

Ripple laminated sand (Sr) composed of quartz, muscovite and biotite minerals. The colour of the sand is grayish white and the thickness varies from 5cm to 45 cm. It is exposed at Doahni, Bhotemari, Laxmitari, Khuniagachch, Bazra, Tapa Kharibari, Dalia Bazar, Tista Bridge, Chawla and Chawla-200 sections and the maximum thickness was recorded at Chawla-200. Very fine sand and coarse sand constitute this facies.

4.1.2.6 Parallel laminated sand facies, Sh

Parallel laminated sand facies (Sh) is composed of gray to yellowish brown, parallel, horizontal or flat bedding, very fine sand to very coarse-grained sand. It overlies massive sand, trough cross stratified sand and ripple laminated sand facies. Sometimes the facies, Sh overlies the massive clay facies. The thickness of parallel laminated sand varies from 10 cm to 80 cm.

4.1.2.7 Clay with silt facies (Fl)

Clay with silt facies (Fl) comprises silt and clay. Clay constitutes 70-75 percent by volume of this facies. Clay is steel gray to brownish gray in colour. Silt with certain amount of very fine sand comprises rest part of the facies Fl. Silt is gray to grayish white in colour. Thickness of Fl range from 5 to 50 cm. Silt in the lower part of the facies is parallel laminated, while that in upper part shows current ripple laminations. The facies sharply overlies ripple laminated sand (Sr), parallel laminated sand (Sh), trough cross stratified sand (St) and occasionally over massive clay (Fm).

4.1.2.8 Massive clay facies (Fm)

Massive clay (Fm) is a major facies, which constitute the upper portion of the litho-column. The material of this facies is generally clay and the colour of the clay varies from bluish gray to grayish white. The clay is sticky when wet. The facies is characterized by mottling nature and ped development. The presence of rootlets is a common feature of the facies, Fm. The facies sharply overlies matrix supported conglomerate, Gms (at Tapa Kharibari Middle Bar, Dalia), massive sand, Sm (at Tapa Kharibari Middle Bar, Chawla-200), trough cross stratified sand facies, St (at Khuniagachh, Dahabandha), parallel laminated sand, Sp (at Tapa Kharibari), ripple laminated sand, Sr (at Doahni, Bazra, Tista Bazar, Chawla, Chawla-200), parallel laminated sand, Sh (at Tapa Kharibari Middle Bar, Dalia, Chawla) and clay with silt, Fl (at Bhotemari, Laxmitari, Khuniagachh, Haripur, Dalia, Tista Bazar). The thickness ranges from 5 to 30 cm and the maximum thickness were found at Bojra (Figure 6.8), Tapa Kharibari Middle Bar and Chawla sections.

Figure 4.8: Massive clay facies (Fm) as exposed in the Tista River Basin, Bojra, Ulipur, Bangladesh.

4.1.2.9 Depositional Environment

Matrix supported conglomerate may be the product of debris flow deposits which are promoted by steep slope and lack of vegetation. Short period of abundant water supply produced by heavy rainfall and/or melting of glacier and it is a source providing debris with a sandy matrix (Bull, 1977; Starkel *et al.* 2015). This flow may be confined to high lobed braided channels but commonly spread out at lobate sheets on the lower reaches of proximal part of the river forming levees and having characteristics of debris flow deposits (Miall, 1978; Blair and McPherson, 1994). Lack of organized fabric is a common aspect of debris flow deposits (Rust and Koster, 1984). Because of its high viscosity the debris flow deposits do not travel longer distance. Hence these deposits are normally observed in proximal fan. Short-term fluctuation of precipitation in fan area undoubtedly produces debris flow in humid area (Curry, 1966; Blair and McPherson, 1994).

The rapid deposition and/or the post depositional deformation result Sm, massive sand beds (McCabe, 1977; Jones and Rust, 1983; Udo and Mode, 2013; Allen, 1986). In the present research area, the production of Sm from the post depositional deformation is irrelevant. This sort of lithfacies reflects the deposition of sediments in a sand-dominated braided channel (Morton *et al.* 2011).

Most commonly the facies, St are the products of migrating sinuous crested dunes or crescent shaped bars on the top of a gravel facies, in combination with planar cross bedded sand (Sp) facies, or in local depressions of mega ripples reveals the evidence of scour –fill episodes (Miall, 1978; Walker and Cant, 1984). The presence St facies along with the upward as well as down slope of the litho-columns within the Tista Basin area is interpreted as response to shallowing of water over the gravelliferous bars and active gravelliferous braided channels with a decrease of stream competence, accompanied by or in response to migration of active tract of channels over the fan (Wasson, 1977; Reineck and Singh, 1980).

The deposition of Sp facies demarcates the current migration of linear ripple whereas large scale planar cross-bedding is resulted from both, two dimensional mega ripples and sand waves or migration of three dimensional, medium sized subaqueous dunes (Ashley, 1990). Sets of planar cross-bedded sand (Sp) facies associated with other finer facies may also represent chute bars in the lower mid to distal part of the alluvial fan (McGowen and Garner, 1970). Low angle planar cross-bedded sand is common in the fining upward litho-column of water laid deposits (Bull, 1972: Reineck and Singh, 1980).

Ripple laminated sand (Sr) is produced from the migration of small-scale 2D and 3D ripples during low flow condtions in relatively shallower water depth (Jopling and Walker, 1968). The ripples may indicate partial abandonment of channels (Gardis and McCade, 1981). These may be deposited partly filled channels in dying stages within unconfined channels or by sheet floods in the alluvial fan (Reineck and Singh, 1980). These ripples may locally present in the sandy layers within the upper part of the stacked channel deposits of stream dominated lower part and inactive lobes of proximal fan (McGowen and Groat, 1971; Roy *et al.*., 2004a).

Parallel laminated sand (Sh) facies are product of upper part of lower flow regime when the flow velocity was slow (Middleton and Southward, 1978). The coarser nature, unsorted character and faint laminations/horizontal laminations of the sediments are suggestive of flood deposits in the overbank of the Tista River.

These deposits are virtually suspension products in slow moving shallow water (Roy *et al.* 2001). Parallel laminations indicate settling from suspension in the slow moving or stagnant water (Roy *et al.* 2004a). The sediments of Clay with silt facies (Fl) are over bank fine or waning flood deposits. From the field observations, it may be concluded that the coarser sediments (silt and very fine sand) of this facies might have been deposited during the rainy season when the river stage is highest and inundate the floodplains or the bar tops.

The deposits of Massive clay facies, Fm represent well drained swampy environment (Roy *et al.* 2004b). Massive clay (Fm) is the final stage of vertical aggradations in the overbanks possibly in the floodplains, flood basins and back swamps when the velocity of the transporting medium was virtually lean that promotes the deposition of clay materials from suspension.

4.1.2.10 Facies Model

The vertical relationship of different facies can be shown by the construction of facies model. The facies model is a useful tool for better understanding of the stratigraphy of an area. It is the most common figure that provides the genetic explanation of the past geologic processes that played the dominant role for the formation of the facies present in the litho-columns of the Tista River basin (Figure 6.9). A facies model is a general summary of the sedimentary environments represent by the rock record (Walker 1984).

The basal facies Matrix supported conglomerate (Gms) is the Oldest facies which is formed under high energy conditions. Trough cross stratified sands (St) is the products of the migration of 3D sub-aqueous dunes in the deeper part of the channel in relatively high energy conditions. Planar cross stratified sand (Sp) is the product of current migration of linear ripples. Ripple laminated sand (Sr) is formed owing to the migration of small-scale 2D and 3D ripples at the time of low flow strength in relatively shallow water bodies (Jopling and Walker, 1968). Parallel laminated sand (Sh) facies is also a resultant of low energy conditions. Massive sand (Sm) is resulted from transport and deposition by short-lived, sediment flows. Faintly laminated clay with silt (Fl) are the product when the velocity of the running water is comparatively low in shallow water condition in the overbank. Massive clay (Fm) is a product of flood basins and back swamps when the velocity of the transporting medium is lowest and suspension took place.

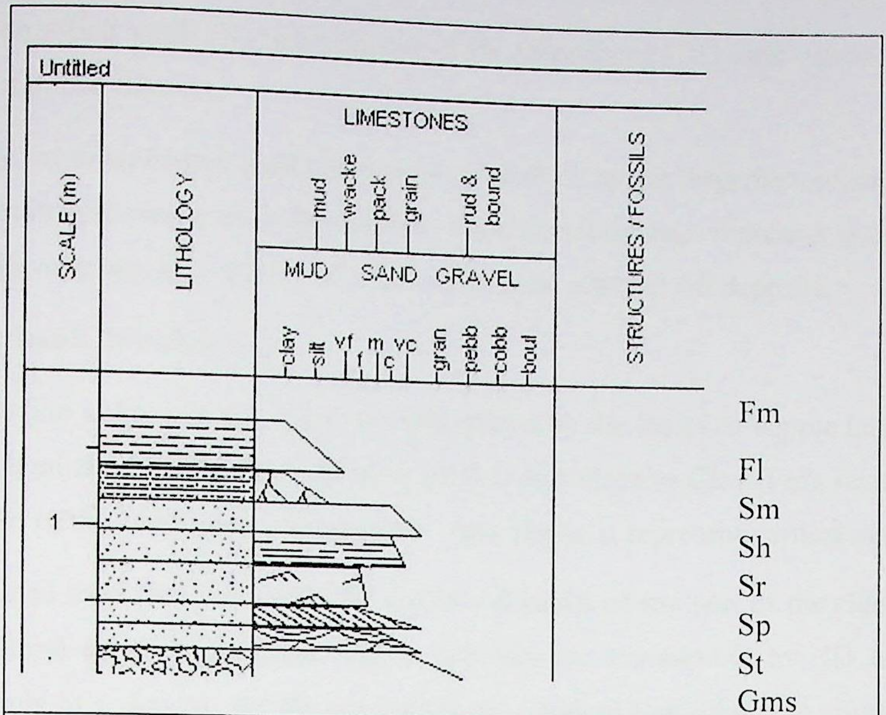


Figure 4.9: Facies model of the Tista River deposits

4.1.2.11 Facies Association

There are two types of facies association are found from the sediments of the studied Tista River. These are as follows—A) Channel deposits and B) Overbank fine or bar top deposits including flood deposits or lean period especially in late winter and early summer, when river flow is sluggish due to scarcity of water supply from upstream. The channel deposits consist of Matrix supported conglomerate (Gms), Massive sand (Sm), Trough cross stratified sand (St), Planar cross stratified sand (Sp), Ripple laminated sand (Sr), whereas, the overbank fines including flood deposits comprise of Ripple laminated sand (Sr), Parallel laminated sand (Sh), Clay with silt (Fl) and Massive Clay (Fm).

4.1.2.12 Channel deposits

The channel deposits are laid down under high energy in the channel. The Matrix supported conglomerate (Gms) deposited under high energy condition having sufficient paleo-slopes to carry the sediments. These sediments represent high energy graveliferous river at piedmont alluvial plain or proximal part of alluvial fan.

The Massive sand (Sm) sediments are tractive current deposits under high energy condition and the deposition took place rapidly that did not allow to develop and sedimentary structure. Trough cross stratified sands (St) are the products of the migration of 3D sub-aqueous dunes in the deeper part of the channel in relatively high energy conditions.

Planar cross stratified sands (Sp) are deposits of the migration of 2D sand waves in relatively shallower part of the channel.

Current ripple cross laminated sand (Sr) has been resulted by the migration of small scale 2D and 3D ripples in shallower part of the channel. The channel deposits represent lateral accretion (point bar), downstream accretion (mid channel bar) and channel fill deposits.

4.1.2.13 Overbank fines/bar top

The overbank fine or bar top sediments are constituted by the facies of Ripple laminated sand (Sr), Parallel laminated sand (Sh), Clay with silt (Fl) and Massive Clay (Fm). occurring in the uppermost part of the sedimentary sequences. These deposits represent vertical accretions.

Ripple laminated sand (Sr) represents the shallow deposits of top part of the channel and the deposits of flood on the overbanks. These deposits are represented by 2D ripples; with sufficient supply of sediments the ripples sometimes climb to form climbing cross ripples.

Parallel laminated sand (Sh) is somewhat coarse in grain size and parallel laminated. These deposits are product of upper part of lower flow regime when the flow velocity is at its minimum condition (Middleton and Southward, 1978). The coarser nature, unsorted character and faint laminations/horizontal laminations of the sediments are suggestive of flood deposits in the overbank of the Tista River.

Faintly laminated clays (Fl) are the products when the velocity of the running water is comparatively low in shallow water condition in the overbank.

Massive clay (Fm) is the final stage of vertical aggradations in the overbanks possibly in the floodplains, flood basins and back swamps when the velocity of the transporting medium was virtually lean that promotes the deposition of clay materials from suspension. These are suspension fall outs of the river and flood in the overbanks. The presence of root/rootlets (in form of small rootlets, decomposed ped marks and coalifed rootlets) are suggestive of short time gap when small scale plants, shrubs and/or grass would grow. The relative abundances of different lithofacies in the area of investigation are shown by Figure 6.10.

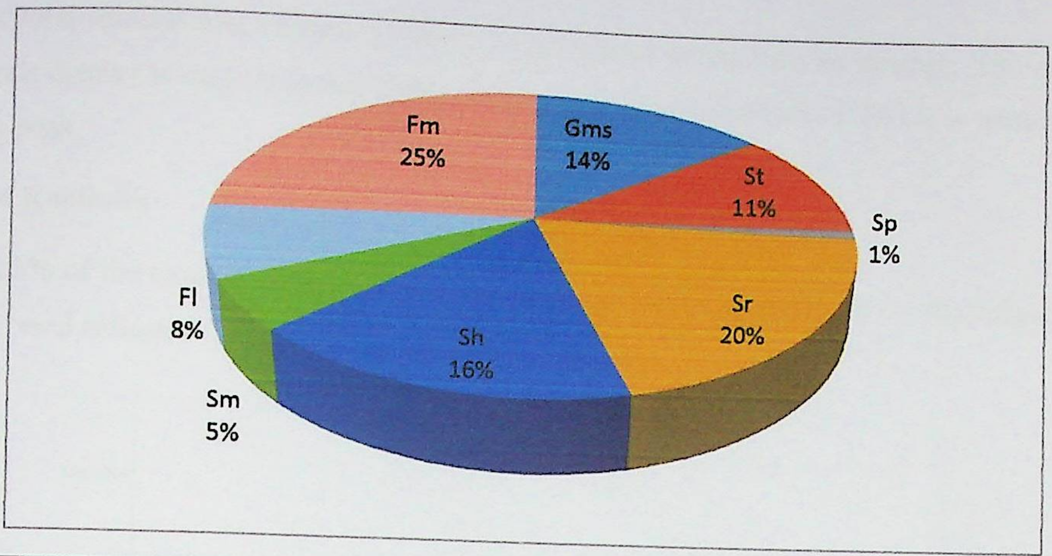


Figure 4.10: The volumetric distribution of different lithofacies of Tista river sediments

4.1.3 Clay Mineralogy

4.1.3.1 Clay Mineral Association

The various members of clay minerals are identified from sediments of the Tista River and adjoining areas and they are namely, quartz, illite or mica in combination with small amounts of kaolinite, chlorite, glauconite and phengite (Table 4.3).

Table 4.3: Relative distribution of clay minerals in total sediments (expressed as percent)

Sample No	Location	Illite	Chlorite	Kaolinite	Quartz	Feldspar
S-4	Shutibari	53.7	6.0	4.7	34.6	1.0
S-2	Mohipur	44.9	6.2	3.4	44.0	1.5
S-1	Pirgacha	40.2	4.9	4.3	49.8	0.8
S-3	Sundargani	30.5	2.8	1.7	59.0	6.0
S-5	Chilmari	10.5	1.7	0.8	83.8	3.2
	Average	**35.9**	**4.3**	**3.0**	**54.3**	**2.5**

4.1.3.2 Illite

The minerals of illite group comprise large quantities of clay mineral and amounts of illite varies from 10.5% to 53.7%. Most dominant illite peak is the basal spacing at 10Å which reveals similar to the basal reflection along (001) plane. The reflections at 4.99Å analogous to (002) are weaker than those at 3.47Å.

4.1.3.3 Chlorite

In the total mineral assemblage, chlorite comprises 4.3 percent on an average. The chlorite minerals display strong reflection along (003) plane. The reflection of 2.82Å is weaker than 4.71Å peak.

4.1.3.4 Kaolinite

About 3% of the total mineral assemblage is kaolinite which is identified by the reflection at 7.08Å basal reflection (Figure 4.11).

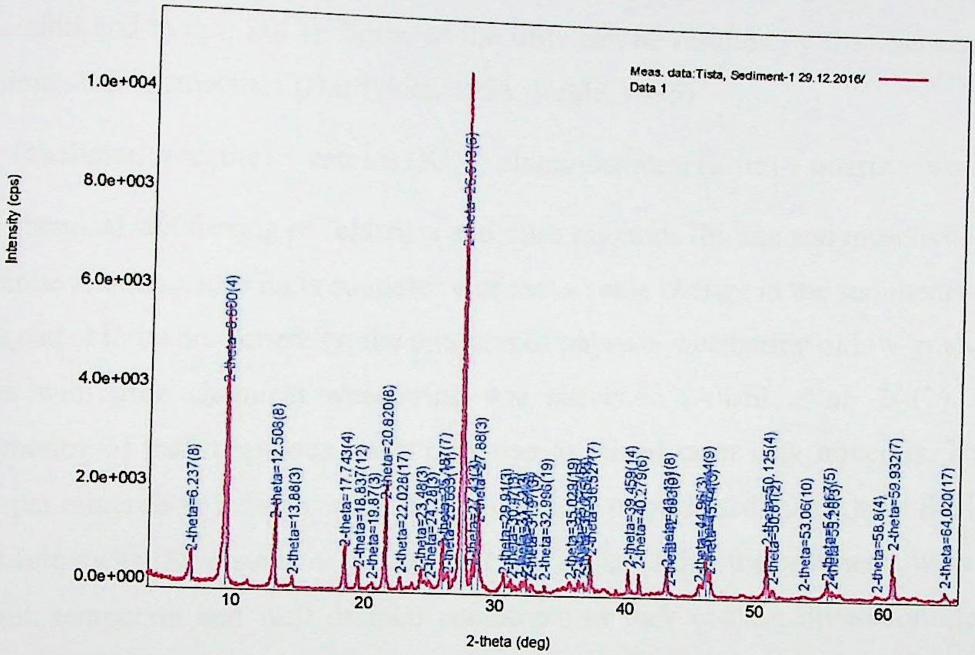


Figure 4.11: XRD pattern of Tista River Sediments at Station Pirgacha, Rangpur.

4.1.3.5 Glauconite

Glauconite is found in minor quantities from the sediments of Mohipur and Chilmari.and identified at basal reflections 10.011Å –10.043Å.

4.1.3.6 Non-clay Mineral Assemblage

Quartz comprises 54.3% of the total sediments and it is identified by basal reflection 4.25Å. The quantity of clay minerals is inversely proportional to that of quartz. In the study, 2.5% of the total mineral is feldspars that are identified at basal reflections 6.375-6.384Å. One of the As-bearing mineral named as lavendulan is identified from two locations (Nilphamari and

Gaibandha) was identified in trace amounts. The peaks at which lavendulan are identified are 10.054 and10.072Å. The other minerals include enstatite, lepidolite etc.

4.1.3.7 Discussion

Clay minerals are resulted owing to weathering from the pre-existing rocks. In the Tista river deposits, the most common clay minerals are illite or muscovite with minor quantities of kaolinite and chlorite and trace amounts of interlayer clay minerals like illite/smectite. Illite might have been originated by the mechanical weathering of the primary micaceous minerals or as secondary minerals from the chemical dissolution of muscovite and feldspar minerals (Chaudhri and Singh, 2012). Some of the illite can be resulted by the chemical alteration of kaolinite and/or smectites (Bjorlykke, 1998; Velde, 1995).

clay (kaolinite, smectite) + cations (K^+) = aluminosilicate (illite) + quartz + water.

The chemical weathering of feldspars and mica minerals (biotite and muscovite) also produce kaolinite and the kaolinite is suggestive of remarkable change in the sediments (Paolo, 2010). Illite and chlorite are generally, the products of physical weathering of low-grade metamorphic rocks with little chemical weathering and alteration (Alizai *et al.* 2012). The chemical weathering of mafic igneous rocks give rise to mixed layer clay minerals. The presence of feldspar minerals is indicative that the provenance of these sediments have the influence from the basic rocks (Srivastava *et al.* 2013). It is concluded that the sediments were formed under humid, temperate and well drained conditions as they contain illite-kaolinite clay mineral associations (Aftabuzzaman *et al.* 2013).

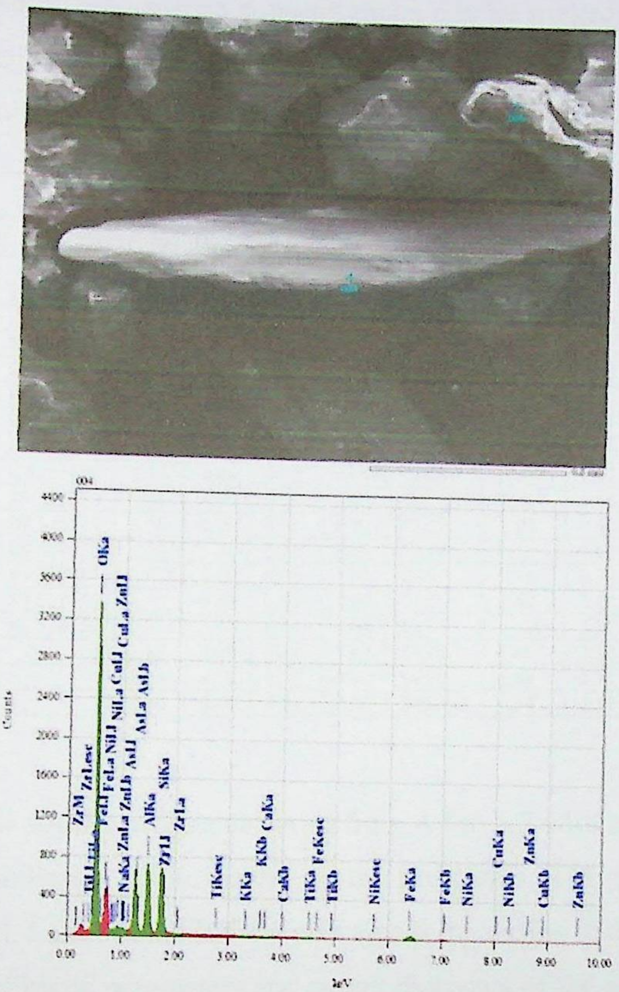
4.1.3.8 Illite crystallinity (IC) index

The illite crystallinity (or the illite crystallization index, IC) is a key index for the explanations whether the illite is mechanically or chemically formed. The hydrolysis of illite expands its spacing between the layers and is influenced by high precipitation and warmer temperature conditions which promotes the chemical dissolution (Singer, 1984). A lower illite crystallinity index suggests a smaller spacing between illite layers, which in turn referred to a more crystallized, mechanically sourced illite. A higher crystallinity value indicates less-crystallized illite, and its derivation from diagenesis of primary minerals (Paolo, 2010).

The numerical value of the illite crystallinity index ranged from 0.228 to 0.345, suggesting that the illites are relatively well crystallized and indicates the illite sources from the physical weathering of primary rock materials (Jaboyedoff *et al.* 2001).

4.1.4 The EDS study of the Sediments

The EDS study shows the presence of heavy metals such as As, Fe, Zn in the sediments of the study area.



Element	(keV)	Mass%	Sigma	Atom%	Co
O K	0.525	58.12	0.36	77.20	
Na K	1.041	0.21	0.05	0.19	
Al K	1.486	8.74	0.16	6.88	
Si K	1.739	10.13	0.18	7.66	
K K					
Ca K					
Ti K	4.508	0.30	0.09	0.13	
Fe K	6.398	13.76	0.75	5.23	
Ni L	0.851	1.66	0.30	0.60	
Cu L	0.930	1.00	0.09	0.33	
Zn L	1.012	0.82	0.15	0.27	
As L	1.282	5.27	0.22	1.49	
Zr L					
Total		100.00		100.00	

Figure 4.12: The EDS study reveals the presence of heavy metals like As, Fe, Zn in the sediments

4.1.5 Geochemistry of the Sediment

The geochemical analyses of the sediments of the aquifers of the study area reveal that iron is the most abundant metal among the analyzed heavy metals and zinc is the less common metal (Table 4.4). The trend of the average concentrations can be ranked as Fe>As>Cu>Zn. The mineralogy of the clay sized particles (<2μm) reveals that quartz and illite with minor amounts of chlorite and kaolinite are the dominant minerals. A rare As-bearing mineral, lavendulan is identified which is a copper arsenate.

Table 4.4: Results of geochemical analyses of the sediments of the study area

Sl No.	Location	Longitude	EC	pH	TOC	TN	S	P	Cu	Zn	Fe	As
			ds/m		%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
1	TAPAKHARIBARI	88.950963	1.46	4.70	0.43	0.04	70.90	5.65	3.08	0.32	25840.80	2.99
2	KHARIBARI	88.957194	2.22	4.40	0.71	0.06	104.57	5.23	2.26	1.08	24367.40	2.82
3	DALIA	89.035134	0.44	4.60	0.20	0.02	7.34	5.52	1.96	0.38	27875.20	3.62
4	DOAHNI	89.089465	0.55	5.40	0.16	0.01	5.71	4.45	0.22	0.52	25688.80	2.19
5	VOTEMARI	89.161820	1.14	5.50	0.16	0.01	46.45	4.86	0.40	0.34	25384.80	2.92
6	LAXMITARI	89.251106	2.39	4.60	0.12	0.01	118.21	15.03	5.62	0.80	26682.80	3.75
7	MOHIPUR	89.252050	0.76	4.50	0.35	0.03	143.55	7.10	3.86	1.92	27891.00	5.77
8	KHUNIAGACHH	89.345713	0.96	4.70	0.16	0.01	37.27	4.19	0.44	0.24	24841.00	3.70
9	MARAIRHAT	89.409958	1.30	5.30	0.20	0.02	72.47	5.37	0.50	0.34	25384.80	2.91
10	KAUNIA	89.430932	0.47	4.70	0.20	0.02	2.58	6.14	0.34	0.52	27115.20	4.50
11	SHIBDEB	89.521515	1.75	5.40	0.62	0.05	71.04	7.49	3.04	0.48	27781.80	4.43
12	SUNDARGONJ	89.536750	0.53	5.40	0.47	0.04	20.47	11.29	3.80	0.78	26875.60	2.64
	Mean		**1.16**	**4.93**	**0.31**	**0.03**	**58.38**	**6.86**	**2.13**	**0.64**	**26310.77**	**3.52**
	Median		**1.05**	**4.70**	**0.20**	**0.02**	**58.68**	**5.59**	**2.11**	**0.50**	**26261.80**	**3.31**
	Variance		**0.42**	**0.16**	**0.04**	**0.00**	**2000.05**	**9.37**	**2.92**	**0.20**	**1372709.53**	**0.92**

4.1.5.1 pH

The pH of the shallow aquifer sediments varies from 4.4 to 5.5 with an average value of 4.93. The low pH value indicates acidic nature of the sediments. The optimum pH value was measured in Votemari, Lalmonirhat and the pH value is increasing in the downstream direction (Figure 4.13a). The climatic parameters and parent materials of the sediments control its pH. Acidic sediments are common in the areas of high rainfall. Moreover, the sand particles comprise the sediments of the investigated area.

4.1.5.2 Electrical conductivity (EC)

Maximum EC of the examined sediments is 2.39 ds/m which was recorded in Gangachara of Rangpur district (Figure 4.13b). The lowest EC value of the sediments was found in Dalia, Nilhamari district that was 0.44 ds/m (Table 4.4). The mean EC value of the sediments was 1.16 ds/m that indicates very low or negligible effects of salinity of the sediments of the Rangpur division (SRDI, 2010: Kumar *et al.* 2019).

4.1.5.3 Total Organic Carbon (TOC)

The amount of total organic carbon varies from 0.117% to 0.709% which is very low. The median value of TOC 0.195%. The sediments of Recent age contain low concentrations of TOC. The amount of TOC is slightly increasing in the farthest part of the Tista fan.

4.1.5.4 Total Nitrogen (TN)

The concentrations of nitrogen in the sediments of the investigated area are very low which ranges from 0.01% to 0.061%. The average concentration of N is 0.0268%. The distribution of the total nitrogen is the lowest in the middle portion of the studied area. Eighty-six percent of Recent sediment of the Brahmaputra floodplain have nitrogen deficiency (Moslehuddin 1993: Moslehuddin *et al.* 1997).

4.1.5.5 Sulphur (S)

The average amount of sulphur is 58.38 mg/kg that ranges from 2.58 mg/kg to 143.55 mg/kg. The amount of sulphur is decreasing in the distal part of the river that implies that the source of sulphur is the Himalayan Mountain Range.

4.1.5.6 Phosphorus (P)

The average phosphorus content of the aquifer sediments is very low whose numerical value is 6.86 mg/kg. The maximum amount of phosphorus is recorded as 15.03 mg/kg in Laxmitari, Gangachara whereas the lowest value is 4.19 mg/kg in Khuniagachh, Lalmonirhat. The amount of phosphorus is increasing in the lower part of the floodplain area which indicates of the phosphorus may be derived from the anthropogenic activities especially from phosphate fertilizer.

4.1.5.7 Copper (Cu)

The median concentration of copper is 2.11 mg/kg. The amount of copper varies from 0.22 mg/kg to 5.62 mg/kg in the sediments of the studied area.

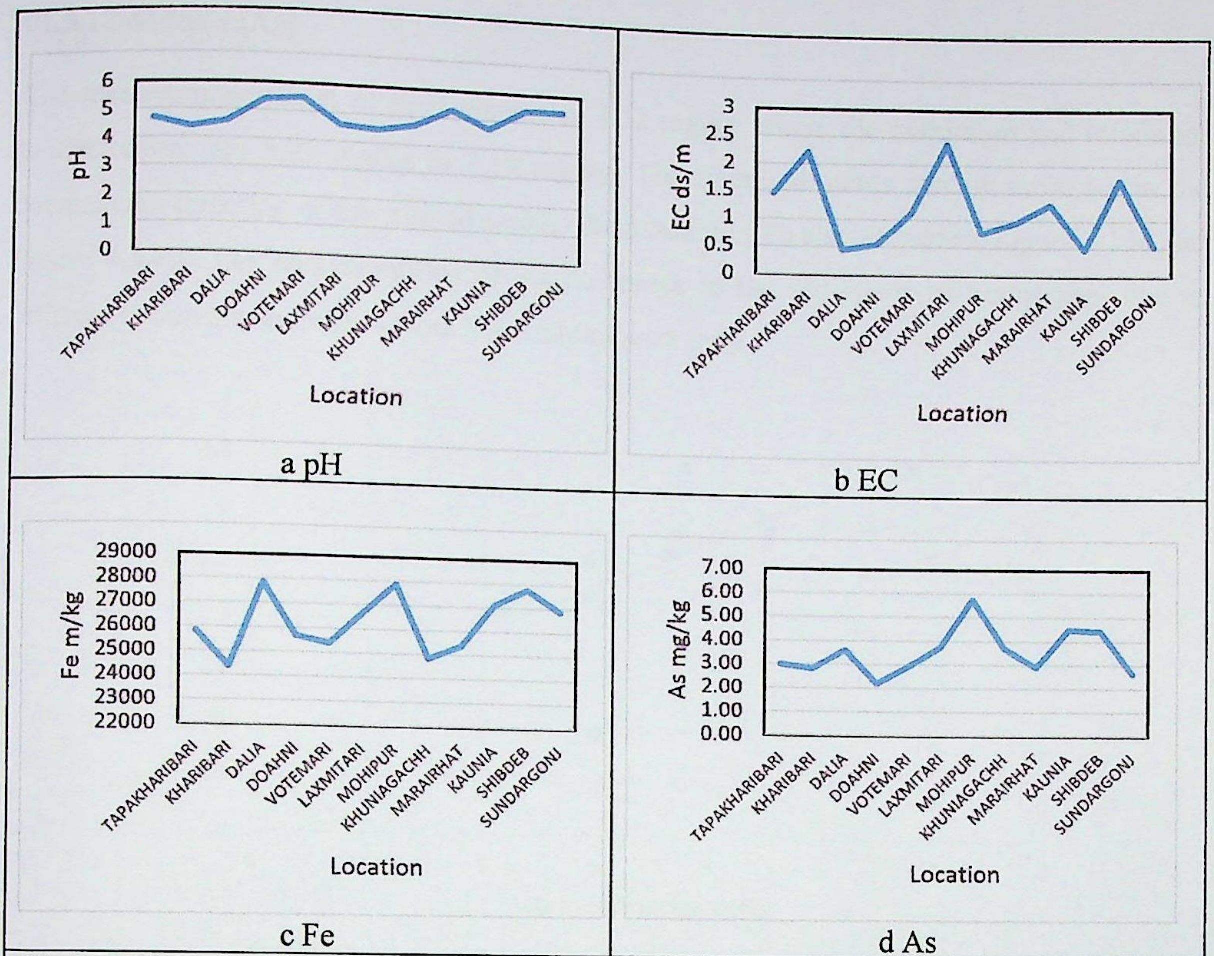


Figure 4.13: Spatial distribution of pH, EC, Fe and As in the sediments of the investigated area.

4.1.5.8 Zinc (Zn)

The Zn content of the investigated sediment samples varies from 0.24 mg/kg to 1.92mg/kg, with the mean concentration of 0.643 mg/kg. The optimum Zn content is 1.135mg/kg, only one of the sediments exceed the optimum Zn content (BARC, 2018).

4.1.5.9 Iron (Fe)

Chemical weathering and erosion of mountain belts influence the distribution of trace metal influx to the ocean, sediments were carried by the rivers and subsurface water flow (Zahid et al. 2008; Dowling et al. 2003). The concentrations of iron vary from 24367.4 mg/kg to 27891mg/kg with the mean concentrations of 26310.77 mg/kg. The sediments of the investigated area are characterized by the fining nature in the downstream direction (Figure 4.13c). The concentrations of total iron increase in the downstream direction of the Tista River with the fining natures of the sediments.

4.1.5.10 Arsenic (As)

The mean concentration of total arsenic is 3.52 mg/kg where the maximum and minimum concentrations are 5.77 mg/kg to 2.19 mg/kg. The finer sediments contain more As in the downstream direction of the studied area as the amount of Fe also increases (Figure 4.13d and Figure 4.13e). The concentrations of As decreases in the sediments of Sundarganj due to influxes of coarser sediments from the Brahmaputra river.

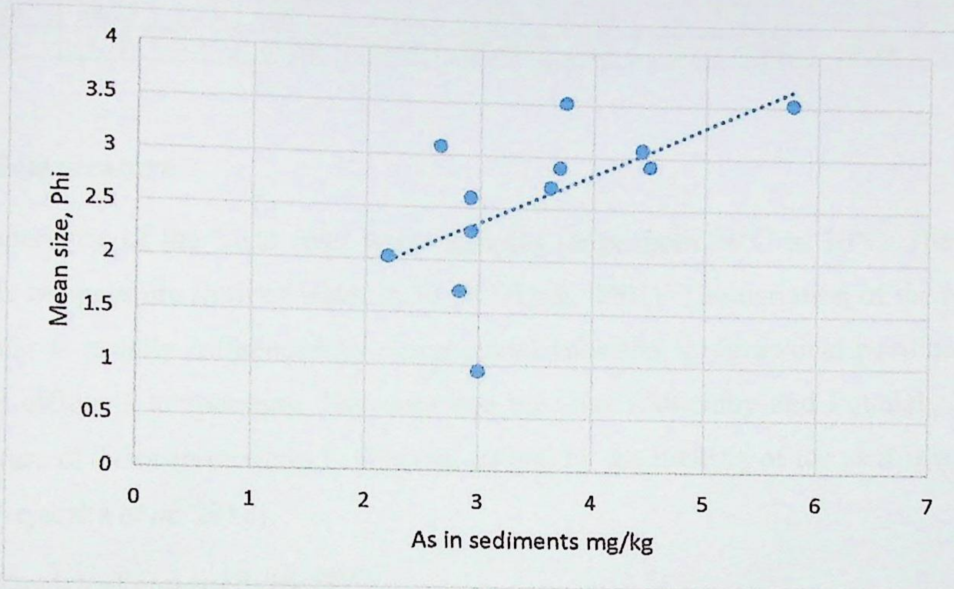


Figure 4.13e: The correlations of As in sediments and mean size of the sediment.

4.2 Hydrogeochemistry

4.2.1 Hydrogeochemistry of Tista river water

4.2.1.1 pH

The pH values of the river water samples vary between 7.7 to 8.5 (Table 4.5). The average value of pH of the riverwater is 8.15 and the standard deviation is 0.33. The permissible pH value of water for irrigation is 6.5-8.5 (Ayers and Wescot, 1985), drinking purposes is 6.5-8.5 and domestic purposes is 6.5-8.5 (De 2005). The higher concentrations of chloride and bicarbonate in the riverwater provides the higher pH that is indicative of the alkaline nature of the Tista river water.

TABLE 4.5: Physico-chemical parameters of the river water, Tista river.

Location	Temperat ure	pH	EC	TDS	Na	K	Ca	Mg	Cl	SO_4	HCO_3
Units	°C		µS/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Dimla	30	8.2	124	83	11.5	2.34	4	21.87	6.9	2.9	33.5
Gangachara	26	8.2	137	92.3	23	2.34	4	14.58	27.6	2.52	18.3
Kaunia	29	7.7	207	139.1	69	2.34	4	7.29	31.1	4.08	21.3
Chilmari	28	8.5	125	84	23	1.95	8	4.86	20.7	4.02	57.9
Average	28.25	8.15	148.25	99.6	31.625	2.242	5	12.15	21.575	3.38	32.75
STDEV	1.70	0.33	39.60	26.66	25.49	0.19	2	7.68	10.69	0.79	18.00

4.2.1.2 Temperature

The temperature of the Tista river water samples range from 26°C to 30°C. The maximum allowable temperature limit of water is 30.5°C (DoE, 2001). The variation of the temperature river water is usually influenced by the seasonal variation, geographical position, sampling time and effluents temperature that enter into the river (Ahipathy and Puttaiah, 2006). The temperature of Tista river water is also maintained by the melting of ice as it is a glacier fed river (Wiejaczka *et al.* 2018).

4.2.1.3 Electrical conductivity (EC)

The magnitude of (EC) of four sampling stations ranged from 124 µS/cm to 207 µS/cm. The average value of EC is 148.25 µS/cm and the standard deviation was recorded 39.60 µS/cm.

4.2.1.4 Total dissolved solids (TDS)

The TDS is the sum of all dissolved components (both inorganic and organic) in water. The TDS of river river waters of the investigated area varies from 83 mg/l to 139.1 mg/l. The mean value of TDS is 99.6 mg/l and the standard deviation is 26.66 mg/l.

4.2.1.5 Sodium (Na^+)

The concentrations of sodium vary from 11.5 mg/l to 69 mg/l. The mean value of Na is 31.625 mg/l and the standard deviation of 25.50 mg/l. Sodium in the river water mainly obtained due to the dissolution of Na-bearing silicate minerals like plagioclase feldspar, feldspathoid, mica, clay minerals and halite (Khan *et al.*, 2014).

4.2.1.6 Potassium (K^+)

The mean potassium value is 2.24 mg/l and the standard deviation of 0.195 mg/l. The concentrations of K range from 1.95 mg/l to 2.34 mg/l.

4.2.1.7 Calcium (Ca^{2+})

The maximum concentration of calcium (Ca^{2+}) is 8.00 mg/l, minimum Ca concentration is 4.00mg/l and the median value for Ca concentration is 4.00 mg/l.

4.2.1.8 Magnesium (Mg^{2+})

Maximum amount of magnesium is found in the river water of Dimla, Niphamari, 21.87 mg/l and the lowest Mg concentration is reported in the river water of Chilmari, Kurigram whose value is 4.86 milligrams per liter. The median value of Mg is 10.935 milligrams per liter.

4.2.1.9 Bicarbonate (HCO_3^-)

The concentrations of bicarbonate in the river water samples range from 18.3 to 57.9 milligrams per liter. The average bicarbonate content of river water is 32.75 milligrams per liter with standard deviation value of 18.00 milligrams per liter. On the basis of average concentration of anions bicarbonate ion appeared as the highest anion in river water.

4.2.1.10 Chloride (Cl^-)

Average concentration of Cl^- in river water of current study is 21.57 milligrams per liter. The chloride contents of river water of the Tista range from 6.90 to 31.1 milligrams per liter.

4.2.1.11 Sulphate (SO_4^{2-})

The oxidation of mercasite and pyrite can contribute sulphate to the natural water (Rahman *et al.* 2012; Matthess, 1982). SO_4^{2-} of the river water ranges from 2.52 to 4.08 milligrams per liter. The average value of sulphate (SO_4^{2-}) concentration of the studied river water is 3.38 milligrams per liter. The chemical weathering of anhydrite may release sulphate ions to the river waters.

The average concentrations of major cations generally follow decreasing order as $Na^+ > Mg^{2+} > Ca^{2+} > K^+$. Sodium and magnesium account for 85.80% of the total cations on an average. Calcium and potassium are less predominant cations and together comprise only 14.19% of the total cations.

The study of cations changes in the longitudinal section of the Tista River revealed that the dewatering of the Tista River for irrigation purposes at Tista barrage might have influenced the cation concentrations of the river water to the increase of sodium and calcium and the slightly decrease of Mg^{2+} and K^+ ions.

The concentration of sodium cation is the lowest in the Tista river in the upstream direction where it entered in Bangladesh and showing the increasing trend after the Tista Barrage where the river is flowing to the lower level. The higher concentration of sodium might be resulted from the reduced discharge of river water, agricultural effluents, erosion of agricultural soils and/or dissolution of silicate minerals and halite (Wiejaczka *et al.* 2018).

4.2.1.12 Hydrogeochemical Facies

The Schoeller semi-logarithm diagram deciphers major ion analyses to show different hydrochemical water types. This graphical representation has the advantage that unlike Piper diagrams, actual samples concentration are exhibited and can be made comparisons (Talabi *et al.* 2015). The Schoeller semi-logarithm plot reveals that Mg and Na cations are dominant metal ions while Cl^{-1} and HCO_3^{-1} are major anions in river water (Figure 4.14).

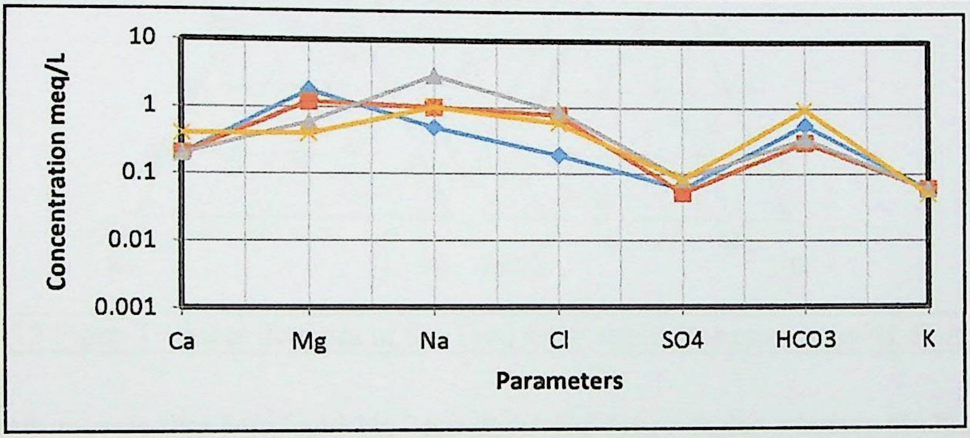


Figure 4.14: Schoeller plot for the Tista river water.

The Piper diagram (Piper, 1944) is used to explain the water types of the Tista river (Figure 4.15).

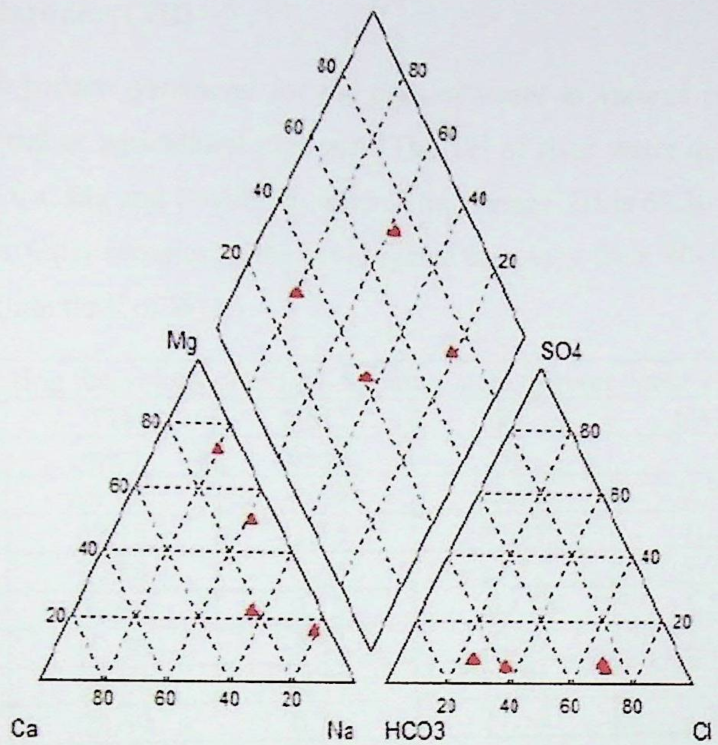


Figure 4.15 Piper-Trilinear diagram of the Tista river water, Rangpur division, Bangladesh.

The diagram reveals that Mg^{2+} and Na^{+} are dominant cation facies whereas the bicarbonate and chloride are the dominant anion facies (Table 4.6). This suggests that dissolution of rocks and groundwater discharge influence the hydrochemistry of the Tista river (Wiejaczka *et al.* 2018). The rate of chemical weathering is related to the particle size of the sediments (Israeli and Emmanuel, 2018).

Table 4.6 Hydrochemical facies distribution

Water facies	**No of Samples**
Mg-Na-HCO_3	1
Mg-Na-Cl	1
Na-Mg-Cl	1
Na-Mg-Ca-HCO_3-Cl	1

4.2.1.13 Evaluation of river water for irrigation purposes

Water criteria for irrigation depend on the chemical composition, the nature of the crops to be irrigated, soil type, climate condition and irrigation and drainage pattern (Uddin *et al.* 2014).

4.2.1.14 Total Hardness (TH)

The TH is an important parameter for the uses of water in various purposes, for example domestic, industrial or agricultural purposes. The TH of river water derives from the excess concentration of Ca, Mg and Fe salts in water. The average TH is 62.30 mg/l (Table 4.7). The TH values of the water samples of the investigated area vary from 40-100 mg/l which is less than the permissible limit of WHO.

Table 4.7: Showing the values of irrigation parameters of river water of the study area.

Location	TH	RSC	PI	SAR	SSP
unit	mg/l	meq/l	%		%
Dimla	99.63	-1.44	49.77	0.50	21.93
Gangachara	69.75	-1.10	64.61	1.20	43.17
Kaunia	39.88	-0.45	94.55	4.75	79.32
Chilmari	39.92	0.15	109.75	1.58	56.80
Average	62.30	-0.71	79.67	2.01	50.31
Median	54.84	-0.77	79.58	1.39	49.99
STDEV	28.59	0.71	27.37	1.88	24.08
	Soft-75% Moderately soft-25%	Safe-100%	Suitable-100%		

4.2.1.15 Residual Sodium Carbonate (RSC)

The concentrations of bicarbonate and carbonate determines the suitability of water for irrigation (Reddy 2013). One of the empirical methods was based on the assumption that calcium and magnesium carbonate precipitation, considering this hypothesis Eaton, 1950 proposed by the concept of residual sodium carbonate (RSC) for the measurement of high carbonate waters. RSC determines the hazardous effects of bicarbonate and carbonate on the quality of river water for agricultural purpose.

The mean value of RSC is -0.71 meq/l. According to US Salinity Laboratory, 1954 the magnitude of all the river water samples were less than 1.25 meq/l, which is an indicative of safe river water quality for irrigation.

4.2.1.16 Permeability Index (PI)

The permeability of soil is influenced by the continuous application of irrigation water. The amounts of sodium, calcium, magnesium and bicarbonate ions in the soil are increased by the use of irrigation water (Chandu *et al.* 1995). The permeability index (PI) is a measure of the suitability of river water for irrigation purpose. The permeability index (PI) is ranked as class I (>75%), class II (25-75%) and class III (<25%). The water under class I and class II is designated as good for irrigation that have PI 25% and above, while class III waters has PI value less than 25% and unsuitable for irrigation purposes (Doneen 1964; WHO 1989). The permeability index of all the river water of the investigated area is 50% and above, whereas they fall in class I and class II, which are suitable for irrigation purposes.

4.2.1.17 Sodium Adsorption Ratio (SAR)

The U.S. Salinity Laboratory demonstrated SAR reasonably estimates the degree to which irrigation water tends to enter into cation-exchange reaction in soil. High magnitude of SAR implies a hazard of sodium replacing absorbed calcium and magnesium, and damages the soil structure (Khan and Abbasi 2013). The mean SAR value is 2.02 that indicates that the studied water samples are excellent in quality for irrigation purposes.

4.2.1.18 Soluble Sodium Percent (SSP)

The maximum allowable limit of SSP is 60% for irrigation water. Seventy-five percent of the studied river water have the SSP value less than 60%.

4.2.2 Hydrogeochemistry of Groundwater

4.2.2.1 pH

The pH values of the groundwater are in allowable ranges 6.5-8.5 of WHO (1997) and varies from 6.2 to 7.4 that indicates the groundwater are slightly acidic to slightly alkaline Table 4.8. The median value is 6.5. The lack of calcite and granite the host rock of the aquifers are responsible for the low pH of the groundwater (Robins 2002). The pH is controlled the by chemical and biological parameters in ground water (Haque 2009).

4.2.2.2 Temperature

The temperature of the studied groundwater is almost uniform, ranging from 25°C to28°C, and the median value is 26°C, as shown in Table 4.8.

4.2.2.3 EC

Groundwater EC of range from 110 to 1190 µS/cm. Based on the EC values, the groundwater is fresh (<1000 µS/cm) and one sample is slightly salty (>1000 µS/cm).

4.2.2.4 Major Cations and Anions:

The trend of major cations is Na^{+}>Ca^{+2}>Mg^{+2}>K^{+} while trend of the major anions is HCO_3^- >Cl^->SO_4^{-2}. Among the cations, Na^+ is the dominant cation while HCO_3^- is most abundant anions.

4.2.2.5 Sodium (Na^+)

Na^+ content of groundwater range from 11.5 mg/L to 80.5 mg/l and maximum concentration was reported from two wells, one is Kaunia, Rangpur and another from Sundarganj, Gaibandha. Groundwater samples are below the maximum allowable limits of Na of recommended standards of WHO 1997 and EQS 1991.

Table 4.8 Physico-chemical properties of the groundwater sample collected from the adjoining areas of the Tista River, Rangpur division, Bangladesh.

SAMPLE CODE	Latitude	Longitude	DEPTH in meter	TEMPERATURE °C	pH	EC	Na	K	Mg	Ca	Cl	SO4	HCO3
	N	E				µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Shutibari	26.1828	88.9943	22.9	26.0	6.8	140	55.2	11.3	9.7	24.0	69.2	2.0	152.5
Kharibari	26.1956	88.9848	27.4	26.0	6.3	220	23.0	2.3	4.9	8.0	31.1	2.7	70.1
Dalia Bazar	26.166	89.0348	11.0	26.0	6.5	650	69.0	11.7	14.6	20.0	107.2	4.4	143.3
Barakhata	26.2094	89.1092	19.8	27.0	6.4	390	23.0	17.6	9.7	12.0	89.9	17.5	94.5
Bhotemari	26.0266	89.1631	19.8	26.0	6.5	180	11.5	3.5	4.9	8.0	34.6	2.2	51.8
Jaldhaka	26.0166	89.0155	9.1	27.0	6.5	410	55.2	2.7	4.9	20.0	155.7	7.4	106.7
Mohipur	25.8676	89.2537	36.6	27.0	6.6	120	23.0	1.2	2.4	4.0	20.7	7.1	54.9
Haragach	25.8141	89.3278	9.1	26.0	6.4	740	80.5	14.0	7.3	4.0	207.6	5.2	183.0
Dhumghara	25.8216	89.3383	7.6	27.0	6.8	120	11.5	6.2	4.9	8.0	89.9	4.9	39.6
Kaunia	25.7721	89.4243	10.7	26.0	6.2	160	34.5	5.5	9.7	12.0	83.0	11.4	100.6
Lalmonihat	25.9072	89.4366	91.4	28.0	7.2	170	11.5	0.8	4.9	4.0	13.8	3.4	103.7
Tista	25.8063	89.4468	76.2	27.0	6.6	1190	69.0	23.4	17.0	36.0	155.7	23.7	137.2
Powtana	25.6739	89.5025	14.0	27.0	6.4	400	57.5	3.5	7.3	8.0	107.2	18.9	67.1
Shibdeb	25.6724	89.5144	12.2	26.0	7.4	110	11.5	3.1	2.4	4.0	38.0	2.7	64.0
DW college	25.5652	89.5251	18.3	28.0	6.3	490	80.5	6.6	14.6	24.0	124.5	28.2	97.6
Ramdakua	25.5324	89.5693	12.2	26.0	6.3	160	23.0	1.2	4.9	4.0	51.9	1.5	39.6
Rajarhat	25.7983	89.5468	64.0	25.0	6.8	200	23.0	2.3	7.3	8.0	76.1	3.4	94.5
Bojra	25.5680	89.6074	7.6	26.0	7.1	720	46.0	4.3	7.3	20.0	34.6	3.8	128.1
Ramna	25.5725	89.6744	14.6	27.0	6.8	300	34.5	2.3	4.9	12.0	3.4	0.2	85.4
Average				26.5	6.6	361	39.1	6.5	7.5	12.6	78.6	7.9	95.5
Median				26.0	6.5	220	34.5	3.5	7.3	8.0	76.1	4.4	94.5
STDEV				26.0	6.8	140	55.2	11.3	9.7	24.0	69.2	2.0	152.5

The source of Na^+ in groundwater is silicate minerals like feldspar and halite (Khan *et al.* 2014: Mostafa *et al.* 2017: Mazumder *et al.* 1994). The chemical fertilizers contribute sodium to the groundwater (Hem, 1989: Sultana, 2009).

4.2.2.6 Potassium (K^+)

The average K^+ content is 6.51 mg/l, with the range of 0.78-23.4 mg/. About sixteen percent of the groundwaters are above the maximum allowable limit of K^+ for recommended standards of WHO 1997 and EQS 1991. The dissolution of sylvite, K-feldspar are the main source of potassium while the potash fertilizer and decomposition of waste and/or animals are the second contributors in shallow aquifers.

4.2.2.7 Calcium (Ca^{2+})

All of the subsurface water have the calcium concentration below the range as described by Nag, 2009. The groundwater Ca^{2+} contents vary from 4-36 mg/l, where the median value is 8 mg/l. The chemical decomposition of calcite, dolomite, Ca-feldspar and pyroxene minerals release calcium to the groundwater (Ganyaglo *et al.* 2010).

4.2.2.8 Magnesium (Mg^{2+})

The minerals that contribute magnesium to the groundwater are dolomite, amphiboles, pyroxene, olivine, chlorite and micas (Saha *et al.*, 2019: Nag 2009). The Mg^{2+} concentrations of groundwater in the study area vary from 2.4 to 17.0 mg/l with the median of 7.3 mg/l.

4.2.2.9 Chloride (Cl^-)

The principal sources of Cl are halite and sylvite as Cl shows the positive correlations with Na and K in this research area (Figure 4.16 and 4.17) (Saha *et al.* 2019)

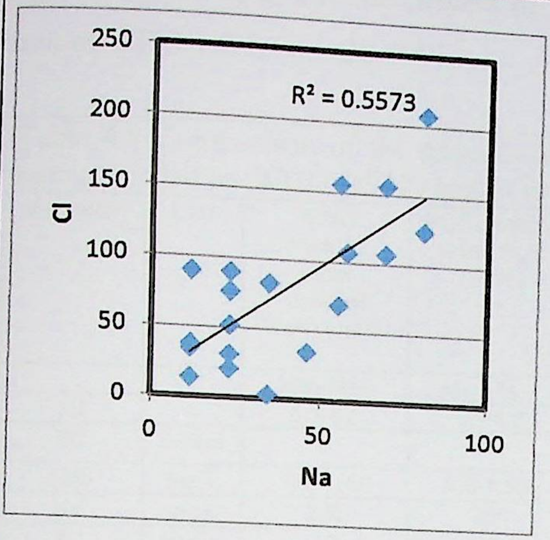


Figure 4.16. Correlation of Na versus Cl

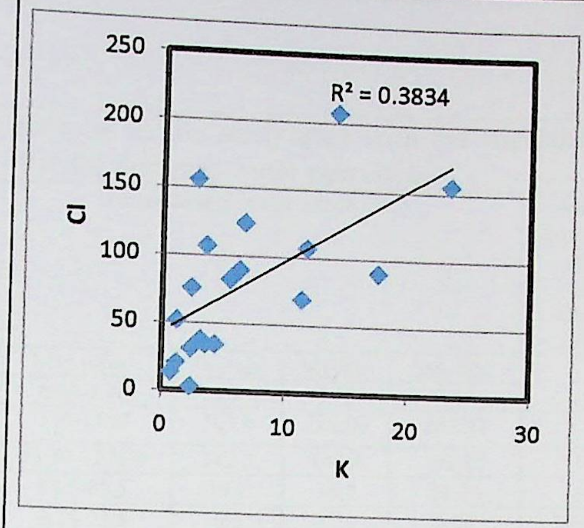


Figure 4.17. Correlation of K versus Cl

4.2.2.10 Sulphate (SO_4^{2-})

The oxidation of sulphur rich minerals release SO_4^{2-} to the groundwater (Matthess 1982; Rahman *et al.* 2012). The SO_4^{2-} concentrations range 0.22 mg/l to 28.22 mg/l. The SO_4^{2-} concentrations of the all groundwaters are within the maximum allowable limit of WHO 1997 and EQS 1991. Bacterial sulphate reduction reduces the amounts of sulphate in groundwater (Kirk *et al.* 2004). The lower SO_4^{2-} concentration of groundwater is an indication of lack of industries in the research area (Mostafa *et al.* 2017).

4.2.2.11 Bicarbonate (HCO_3^-)

The maximum and minimum bicarbonate content are respectively 183 mg/l to 40 mg/l. The oxidation of organic materials in aquifers form carbon dioxide and promotes dissolution of minerals (Khashogji and El Maghraby 2013). The weathering of carbonates increases the concentrations of HCO_3^- (Gastmans *et al.* 2010). Higher bicarbonate contents are found from in the north and central portion of the research area.

4.2.2.12 Water Quality Assessment for drinking

Table 4.9 shows the comparison of pH, TDS, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^- and CO_3^{2-} values of groundwater with the recommended values by the World Health Organization (WHO 1997) and Environmental Quality Standard for Bangladesh. The groundwater is suitable for drinking. Sixteen percent of the groundwater samples the maximum allowable limit of WHO 1997and EQS 1991.

Table 4.9 Comparison of the groundwater samples of the study area with the standard limits recommended by WHO (1997) and EQS (1991) for drinking water purposes.

Parameter	Unit	WHO drinking water standard WHO (1997)	EQS drinking water EQS (1991)	Groundwater in the studied area				Number of groundwater samples above allowable limit
		Min-Max	Min.-Max	Min.-Max.	Average	Median	Std. dev.	
pH	-	6.5-8.5	6.5-8.5	6.20-7.40	6.6	6.50	0.33	None
EC	µS/cm	-	-	110-1190	361.6	220.00	287.93	-
TDS	mg/L	500-1500	500-1,500	73.70-797.30	242.3	147.4	192.91	None
Na^+	mg/L	200	200	11.5-80.5	39.1	34.5	24.16	None
K^+	mg/L	12	12	0.78-23.8	6.5	3.51	6.26	3 Samples
Mg^{2+}	mg/L	50-150	30-50	2.43-17.01	7.55	7.29	4.122	None
Ca^{2+}	mg/l	75-200	-	4.0-36.0	12.6	8	8.97	None
Cl^-	mg/l	200-600	150-600	3.40-207.60	78.6	76.1	54.94	None
SO_4^{2-}	mg/l	200-400	400	0.22-28.22	7.9	4.38	8.15	None
HCO_3^-	mg/l	-	-	39.6-183.0	95.5	94.5	39.8	-

4.2.2.13 Correlation coefficient matrix (r)

Calcium, magnesium, potassium, chloride, bicarbonate and sulphate have positive correlation with Na (Table 4.10). The EC is directly proportional to the major metal ions and anions. The pH is inversely rational to the Ca, Mg, SO_4^{2-} and Cl^{1-}.

TABLE 4.10: Pearson correlation coefficient of groundwater quality parameters (n=19)

	pH	EC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Fe	Cl^-	HCO_3^-	SO_4^{2-}
pH	1.00									
EC	-0.24	1.00								
Na^+	-0.37	0.75	1.00							
K^+	-0.21	0.47	0.52	1.00						
Ca^{2+}	-0.10	0.54	0.63	0.61	1.00					
Mg^{2+}	-0.34	0.63	0.70	0.73	0.80	1.00				
Fe	0.17	0.14	0.21	0.19	0.29	0.17	1.00			
Cl^-	-0.43	0.53	0.75	0.62	0.39	0.54	0.24	1.00		
HCO_3^-	0.01	0.64	0.73	0.60	0.52	0.57	0.40	0.56	1.00	
SO_4^{2-}	-0.41	0.42	0.51	0.49	0.51	0.67	--	0.51	0.11	1.00

4.2.2.14 Hydrochemical facies in groundwater

The hydrogeochemical facies is interpreted by Piper Trilinear diagram (Piper 1944), which reveals the similarities and dissimilarities among water samples (Todd 1980; Ramesh *et al.* 2014). All of the ions plotted in the diagram are expressed as percent of meq/L. The central part of the figure is diamond shaped denotes the classification of groundwater. The groundwaters are mixed type, with Na, Na-Ca, Na-Mg, Na-Mg-Ca and Na-Ca-Mg are cation facies and chloride and bicarbonate are anion facies (Figure 4.18). The marine transgression of Holocene period is responsible for higher content of Na in groundwater in many areas of Bangladesh (Afroza *et al.* 2009).

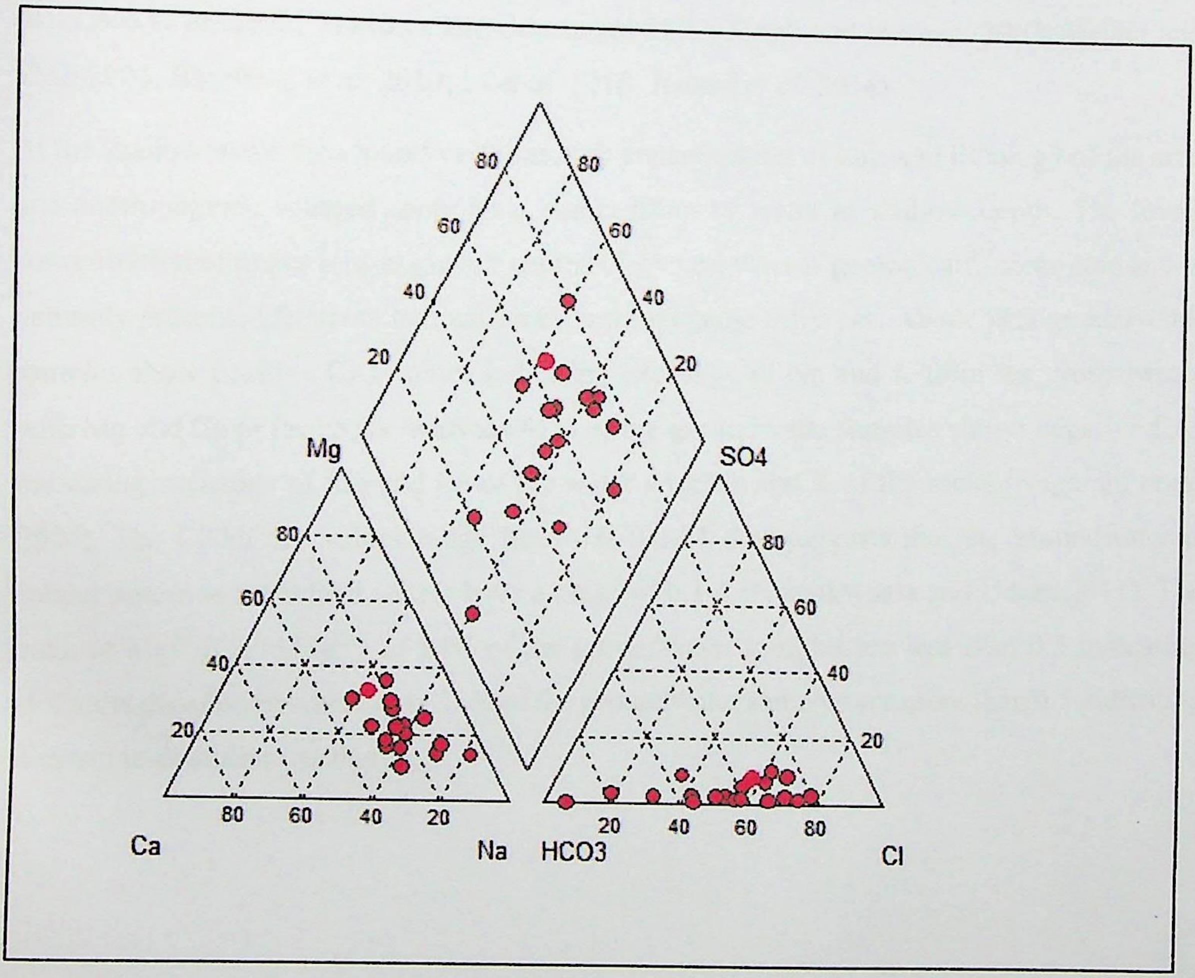


Figure 4.18: Piper-Trilinear diagram of groundwater of the study area.

4.2.2.15 Origin of groundwater

The Tista river origins in the Himalayas, and runs through the Siwalik Group of rocks (Rahman *et al.* 2012). The chemical composition of the sediments has large control on the water quality of the Tista basin. Climate, rock-water interactions, precipitation and evaporation are the dominant factors that influence chemistry of groundwater. Groundwater geochemistry in the investigated area was regulated by the precipitation and chemical weathering of the minerals existing in the source rock (Gibbs 1970). Ion exchange is the principal mechanism, which controls the concentration of chemical composition in groundwater. The anthropogenic activities also have influence on the groundwater chemistry (Apodaca *et al.* 2002; Martinez and Bocanegra 2002; Singh and Hasnain 2002; Jeelani and Shah 2006; Bhardwaj *et al.* 2010; Li *et al.* 2010; Jeelani *et al.* 2014).

At the shallow wells the groundwater has high concentration of ions and lithology of the area and anthropogenic sources control the composition of water at shallow depth. The lower concentration of major ions at greater depths of groundwater is geologically controlled and is naturally preserved from contamination by anthropogenic activities. About 58% groundwater samples show positive CAI values indicating exchange of Na and K from the groundwater with Mg and Ca of the rocks, whereas 42% of the groundwater samples shows negative CAI indicating exchange of Mg and Ca of the water with Na and K of the rocks (Nagaraju *et al.* 2006). The Cl^-/HCO_3^- values range from 0.070-3.91 that suggests that the groundwater is inland waters as the inland waters have a range of 0.1-5 (Nwankwoala and Udom 2011). The ratio of $Mg^{2+}/(Ca^{2+}+Mg^{2+})$ of 84% of the groundwater samples are less than 0.5 indicating dolomite dissolution where only 16% of the groundwater samples are more than 0.5 indicating limestone-dolomite weathering.

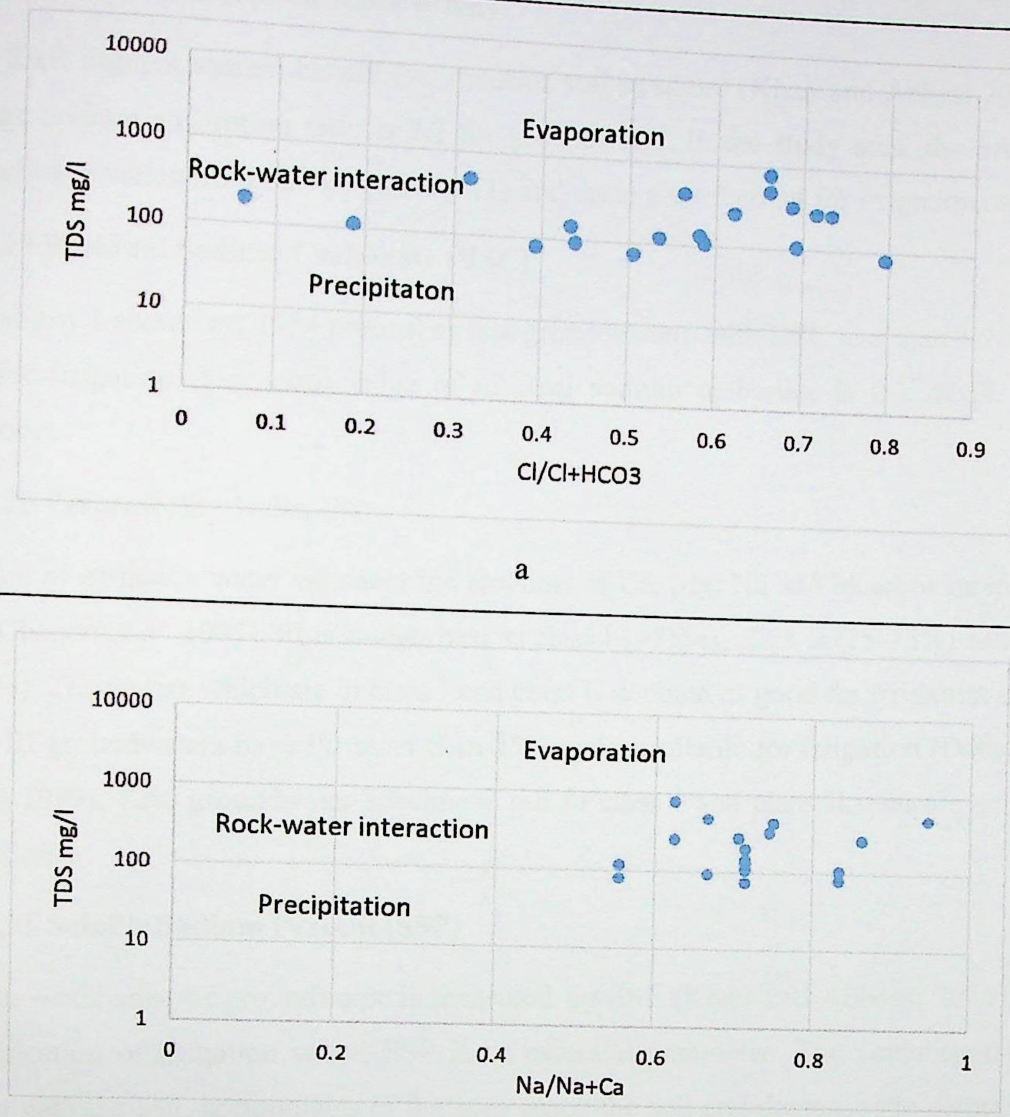


Figure 4.19: Gibbs mechanism of groundwater composition.

4.2.2.16 Irrigation Water Quality

The generally accepted pH for irrigation water is between 5.5 and 7.5.

4.2.2.17 Total Hardness (TH)

The mean TH value is 62.6 mg/l. The TH values of the groundwater varies from 20-160 mg/l that are lower than WHO recommended values (500 mg/l) for drinking water purposes (Islam *et al.* 2016).

4.2.2.18 Sodium Adsorption Ratio (SAR)

High SAR implies sodium hazard that deforms soil structure (Khan and Abbasi 2013). The average sodium adsorption ratio is 2.2 for groundwater. In the study area, the SAR of the groundwater varies from 0.8-5.5 (table 4.11) and these are excellent for irrigation use.

4.2.2.19 Residual Sodium Carbonate (RSC)

US Salinity Laboratory, 1954 prescribes that groundwaters with RSC less than 1.25 meq/l is safe for irrigation. The mean value of residual sodium carbonate is 0.3 meq/l, safe for irrigation.

4.2.2.20 Permeability Index (PI)

The use of irrigation water enhances the amounts of Ca, Mg, Na and bicarbonate ions in the soil (Chandu *et al.* 1995). PI is categorized as class I (>75%), class II (25-75%) and class III (<25%). The waters which are in class I and class II denoted as good for irrigation and while class III groundwaters have PI lower than 25% and unsuitable for irrigation (Doneen 1964; WHO 1989). 72% groundwater specimens fall in class I and class II, and are suitable for irrigation.

4.2.2.21 Soluble Sodium Percent (SSP)

Cation—exchange of groundwater is measured by SSP (Khan and Abbassi 2013). For the classification of irrigation water, SSP is an essential parameter. The water containing Na reacts with the soil, accumulates in the pore space the soil and decrease the permeability of the soil. For irrigation water the required SSP value is 60%. Sixty-eight percent of the groundwater have the SSP values less than 60% and are applicable for irrigation.

4.2.2.22 Magnesium Hazard (MH)

Magnesium and Ca ions are important for plant growth but ehese cause friability of soil. High concentrations of Ca and Mg in irrigation water increase soil pH, which causes the loss of phosphorus. Magnesium hazard (MH) is less than 50% is considered safe and suitable for irrigation purposes (Szabolcs and Darab 1964). Among the groundwaters, fifty-eight percent samples show MH value less than 50% which are safe and suitable for irrigation purposes in the study area.

Table 4.11: Showing the values of irrigation quality parameters of groundwater.

LOCATION	TH	RSC	PI	SAR	SSP	MH
	mg/L	meq/L	%		%	%
Shutibari	100.0	0.5	90.5	2.4	57.4	40.0
Kharibari	40.0	0.4	115.1	1.6	57.0	50.0
Dalia Bazar	110.0	0.2	87.2	2.9	60.0	54.6
Barakhata	70.0	0.2	93.5	1.2	50.9	57.1
Bhotemari	40.0	0.1	109.4	0.8	42.5	50.0
Jaldhaka	70.0	0.4	98.0	2.9	63.8	28.6
Mohipur	20.0	0.5	139.2	2.2	72.0	50.0
Haragach	40.0	2.2	121.7	5.5	82.8	75.0
Dhumghara	40.0	-0.2	100.4	0.8	45.2	50.0
Kaunia	70.0	0.3	96.0	1.8	54.0	57.1
Lalmonihat	30.0	1.1	164.0	0.9	46.4	66.7
Tista	160.0	-1.0	72.6	2.4	52.9	43.8
Powtana	50.0	0.1	101.4	3.5	72.1	60.0
Shibdeb	20.0	0.7	169.4	1.1	59.2	50.0
DW college	120.0	-0.8	80.8	3.2	60.5	50.0
Ramdakua	30.0	0.1	112.9	1.8	63.2	66.7
Rajarhat	50.0	0.6	112.2	1.4	51.5	60.0
Bojra	80.0	0.5	95.8	2.2	56.9	37.5
Ramna	50.0	0.4	107.3	2.1	60.9	40.0
Average	62.6	0.3	108.8	2.2	58.4	52.0
Median	50.0	0.4	101.4	2.1	57.4	50.0
	Soft 23%	Safe 100%	-	Excellent 100%	-	Safe 58%
	Mod. Hard 61.5%	-	-	-	-	-
	Hard 15.5%	-	-	-	-	-

4.2.2.23 Evaluation of Water Quality for Livestock

For all forms of life water is important. Water carries nutrients, hormones, electrolytes, and waste products and helps for the movement of food through the gastrointestinal tract (Lardner *et al.* 2005). High quality water is required in order to prevent from different diseases, salt imbalance and poisoning from toxic components for livestock (Bhardwaj and Singh 2011). The total dissolved solids (TDS) is the important parameter that used to assess the suitability of any water for livestock. Based on the Australian and UNESCO standards, the TDS value between zeros to 2900 mg/l which is suitable for all the animals (Hamill and Bell 1986; Jeelani *et al.* 2014). In this case, the groundwater is good for livestock purposes as the TDS in groundwater ranged from 74-797 mg/l (Table 4.12).

Table 4.12: Maximum permissible limit of TDS for livestock consumption

Livestock	Highest limit of TDS in mg/l	Range of TDS value in mg/l the study area	Remarks
Poultry	2,860	74-797	TDS values are within the permissible limit for all sorts of livestock
Pigs	4,290		
Horses	6,435		
Dairy cattle	7,150		
Beef cattle	10,000		
Lambs	12,900		

4.2.2.24 Comparison of Riverwater and Groundwater composition

The pH value of riverwater indicate alkaline in nature. The average EC values of groundwater are higher than that of riverwater. The Tista riverwater is characterized by high magnesium content and lower concentration of sulphate (Figure 4.19).

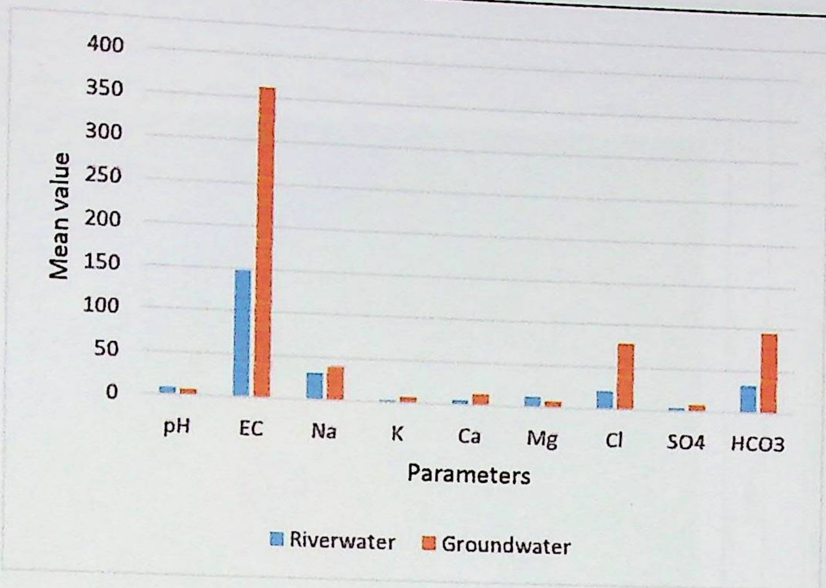


Figure 4.20: Comparison of riverwater and groundwater composition (mean concentration)

4.2.3 Heavy Metal Concentrations of the Tista River water and adjoining areas groundwater

The average arsenic concentration of the river water is 1.3913 µg/l (Table 4.13). whereas that for groundwater is 1.2248 µg/l. The maximum and minimum values of arsenic content of the groundwater are 1.87 µg/l and 0.67 µg/l, respectively (Table 4.14). The findings of the present research work reveals that the arsenic content of the water samples are below the permissible As concentration value of 10 µg/l of WHO, 2008.

Table 4.13: Statistical Summary of Heavy Metal Concentrations of the Tista River water, Rangpur

	Minimum	Maximum	Mean	Std. Deviation
As µg/l	1.15	1.77	1.3913	0.32857
Mn mg/l	0.00	0.11	0.0514	0.05756
Zn mg/l	0.00	0.00	0.0000	0.00000
Fe mg/l	.12	5.74	2.0155	3.22244

Figure 4.21 shows the spatial distribution of arsenic concentrations of water samples of the study area and it is revealed that the As concentration is highest in the central part of the study area.

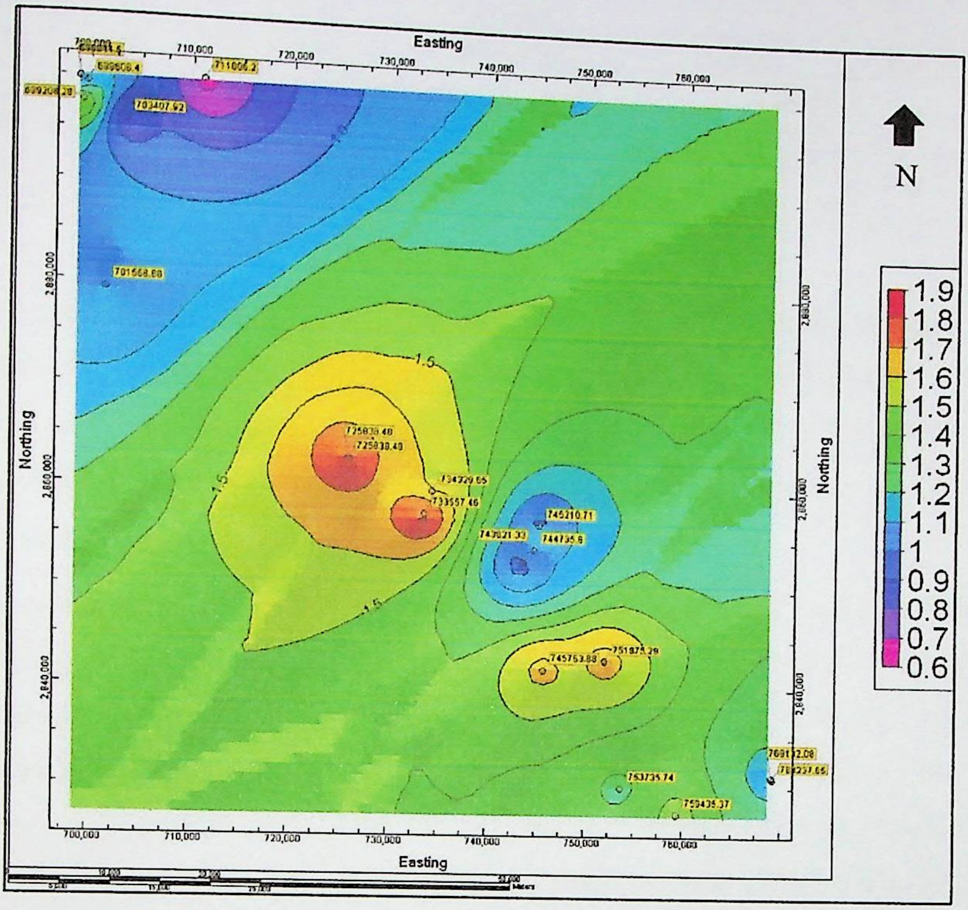


Figure 4.21: Spatial distribution of arsenic concentrations in µg/l of water of the study area.

The present work reveals that the Mn concentrations of groundwaters range from 0 to 1.91 mg/l with the average value of 0.74 mg/l. Eighty percent of the groundwaters exceed the acceptable limit of Mn, 0.10 mg/l for Bangladesh Drinking Water Standard (BD DWS) and 93.33% groundwaters have higher Mn content than the permissible limit of 0.01 mg/L of WHO, 2011. The maximum Mn content of groundwater is reported from Sundarganj Upazila of Gaibandha district. The manganese concentrations of river water samples are lower than the Mn concentrations of groundwater. The mean Mn content value of river water is 0.04 mg/L.

Table 4.14 Statistical Summary of Heavy Metal Concentrations of the groundwater, Rangpur

	Minimum	Maximum	Mean	Std. Deviation
As µg/l	0.67	1.87	1.2248	0.36250
Mn mg/l	0.00	1.91	0.6921	0.58501
Zn mg/l	0.00	0.21	0.0163	0.05134
Fe mg/l	.07	4.79	1.1128	1.21155

The Zn content of all river water samples are zero. In groundwater samples, the zinc concentrations vary from 0 to 0.21 mg/l, with the average value of 0.02 mg/l. The highest amount of zinc is observed from the groundwater of Pirgacha Upazila Rangpur district. The concentration of zinc increases to the downstream direction. The average concentrations of Zn in groundwater are low.

The concentrations of iron in groundwater samples range from 0.071 mg/l to 4.790 mg/l. The mean iron concentrations of groundwater are 1.16 mg/l. The iron concentrations of 1-3 mg/l are acceptable for people drinking anaerobic well-water (WHO 2003). The present study reveals that only one groundwater sample exceeds the maximum acceptable limit of WHO, 2003. The maximum iron concentration is observed from the groundwater sample of Kaunia, Rangpur. The mean iron concentrations of river water are 1.60 mg/l, having the maximum value of 5.74 mg/l in Gongachara, Rangpur.

4.2.4 Arsenic concentration of water and its correlation with sediment arsenic

Arsenic concentration varies from 0.6704µg/l to 1.8692 µg/l with mean concentration of 1.1793 µg/l. The concentration of As both for river and groundwater are below the acceptable limit of WHO (10 µg/l). The arsenic concentration of groundwater shows the positive correlations with the arsenic, iron and copper concentrations of the sediments (Figure 4.21). This implies that the arsenic in groundwater derived from the geogenic source, like the dissolution of arsenic bearing minerals of the aquifer sediments.

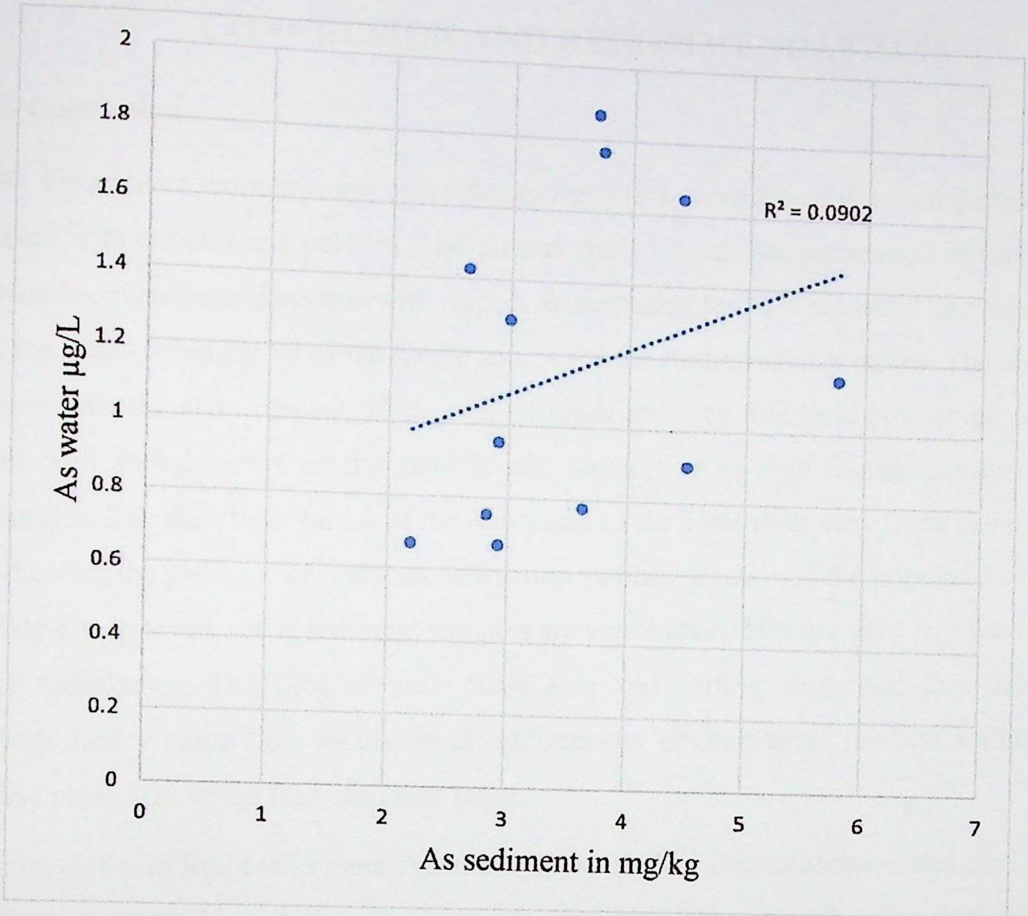


Figure 4.22: The positive correlation between As in sediment and As in groundwater. It reveals that the concentration of As in groundwater increases with the increasing As in the sediments.

CHAPTER: 5
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The Tista River sediments are characterized by the dominance of the sand particles that are mixed with cobbles and pebbles. The present study reveals the percentage of sand decreases towards downstream direction with respect to increasing fraction of mud. The unimodal nature of the sands is indicative of the single source for the studied sand samples. The present study shows that the sixty percent of the studied sands are very fine sand (16 samples out of 26). The well sorted nature of the sand is also suggestive of high transmissivity of the sand particles. The skewness values of the sediments of the Tista river vary from -0.41 to 0.35 that indicating the presence of both coarse fraction and fine fraction in the population distribution. Sixty-five percent of the sediment samples are leptokurtic, 24% are very leptokurtic and 11% are mesokurtic. The plot of both mean size and sorting suggested that the sands are hydraulically controlled, so that in all sedimentary environments the best sorted sediments have mean size in the fine sand size range.

Eight different lithofacies were identified in the studied lithosuccession and they are namely Matrix supported conglomerate (Gms), Massive sand (Sm), Trough cross stratified sand (St), Planar cross stratified sand (Sp), Ripple laminated sand (Sr), Parallel laminated sand (Sh), Clay with silt (Fl) and Massive Clay (Fm).

The colour mottling and colour banding are resulted from the mixing of light coloured minerals with dark coloured heavy minerals. Both muscovite and biotite are found in the study area. The channel deposits are laid down under high energy in the channel. The overbank fine sediments are deposited by the facies of Ripple laminated sand (Sr), Parallel laminated sand (Sh), Clay with silt (Fl) and Massive Clay (Fm) occurring in the uppermost part of the lithosuccessions. The presence of root/rootlets (in form of small rootlets, decomposed ped marks and coalifed rootlets) are suggestive of short time gap when small scale plants, shrubs and/or grass would grow. The finer sediments were deposited from the suspension in floodplains or back swamps.

Illite or mica is the dominant clay minerals in the clay sediments of the Tista River floodplain. The other clay minerals are chlorite and kaolinite. The major non-clay minerals are quartz and feldspar. The accessory minerals of the investigated sediments are lavendulan, lepidolite, enstatite, sekaninaite and ferrierite.

The low values of illite crystallinity index indicated that the illites are well crystallized and suggestive of illite sources from the mechanical weathering of primary rock materials.

The present study reveals that the sediments of the study area are acidic in nature which reflects that they are derived from acid rocks. The sand particles comprise the major part of the deposits. The mean EC value of the sediments was 1.16 ds/m that indicates very low or negligible effects of salinity of the sediments of the Rangpur division. The Recent deposits of the Tista River contain low amounts of Total organic carbon. The average concentration of N is 0.0268%. The concentrations of iron vary from 24367.4 mg/kg to 27891mg/kg with the mean concentrations of 26310.77 mg/kg. Sulphur is significantly positively correlated with copper and zinc ($p<0.05$) and insignificantly positively correlated with arsenic content of the sediments that indicates that the copper and zinc occur as sulphide minerals.

The average TDS value of river water is 99.6 mg/l. The Tista river is suitable for irrigation purposes and have low As concentrations.

The study also reveals that the environment sensitive index parameters like pH, EC and the temperature values of the groundwater samples in the study area are within the permissible limit. The mean concentration trend of major cations in the groundwater samples is $Na^{+}>Ca^{+2}>Mg^{+2}>K^{+}$ whereas the major anions is $HCO_3^{-}>Cl^{-}>SO_4^{-2}$. Compared with WHO (1997) and EQS (1991) guideline values for drinking water and public health, it is concluded that the groundwater of the study area is suitable for all drinking and domestic purposes where only three samples exceed the maximum allowable limit of potassium. The allowable concentrations of all chemical parameters suggest that the quality of the groundwater is mainly controlled by geogenic processes. The excess concentrations of potassium in three groundwater samples are resulted from anthropogenic activities like use of fertilizer. Based on total hardness, SAR, RSC, PI, SSP and MH values, it can be summarized that the groundwaters of the investigated area has excellent quality for irrigation purpose. On the basis of Australian and UNESCO standard the groundwater of the study area is also suitable for livestock purposes.

The arsenic concentrations of groundwater ranged from 0.67μg/l to 1.87μg/l and none of the samples exceeded the maximum permissible limit 10 μg/l of recommended by WHO. The concentration of arsenic in groundwater positively correlated with the arsenic concentrations of sediments. The coarser rock particles of the Tista River contain low arsenic and release less arsenic to the groundwater. The wells are safe considering the arsenic concentrations of groundwater due to elevated topography and remarkably higher hydraulic gradients that result more effective groundwater flushing. 93.33% groundwater samples have higher Mn content than the allowable limit of 0.01 mg/l recommended by WHO.

5.2 Recommendations

Further research works can be taken to identify the arsenic bearing minerals of the aquifers and safe removal of Mn from water.

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